The impact of selected orchard management practices on apple (*Malus domestica* L.) fruit quality

by

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Declaration

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Abbreviations

Abbreviations and symbols are defined when first used in the text. This list summarises those most commonly used.

a.i.	active ingredient
ATS	ammonium thiosulphate
BA	benzyladenine
dAFB	days after full bloom
DNOC	dinitro ortho cresol
FB	full bloom
GA	gibberellin
KTS	potassium thiosulphate
L/D	length/diameter
LCSA	limb cross-sectional area
LSD	least significant difference
NAA	naphthalene acetic acid
NAD	naphthalene acetamide
ns	not significant (at P = 0.05)
P	probability
sem	standard error of mean
TCSA	trunk cross-sectional area
TSS	total soluble solids
wAFB	weeks after full bloom

Glossary

adjuvant:	a substance added to a chemical spray that enhances penetration and action of applied chemicals
biennial bearing:	production of a heavy crop one year (*on-year*) followed by a light or no crop the next year (*off-year)*
blossom desiccant:	a caustic substance applied during the flowering period to prevent fertilisation. Acts by burning or desiccating the female reproductive parts of the flower
December drop:	in apples, the final post-bloom shedding of fruits, normally occurring in December in the southern hemisphere (June in northern hemisphere)
Flowering:	as used here, the flowering period extends from the time of emergence of the first flower on the tree until the completion of anthesis of the latest opening flowers
fruit set:	the persistence and development of an ovary or adjacent tissue following anthesis and pollination
full bloom:	in apples this is defined as that stage at which the majority of the flowers are open, and petals are just starting to fall (i.e. petals are visible on the ground or will drop if a branch is shaken lightly)
growth regulator:	term used for any hormone-like compound, whether natural or artificial
king flower/fruit:	in apples, the central flower/fruit in the blossom cluster
pack-out:	proportion of the crop that can be marketed as first quality
russet:	brownish, roughened areas on the skin of fruit resulting from abnormal production of cork tissue which may be caused by disease, insects, other injury or by a natural varietal character
spur:	short branch on which flowers and fruits are borne
strip picking:	all fruit harvested at the same time, regardless of maturity level or colour
thinning:	removal of flowers and/or fruitlets during the flowering and post-bloom period
typiness:	characteristic fruit shape, particularly development and prominence of the calyx lobes in 'Delicious'

Abstract

Orchard profitability and sustainability are largely dependent on the proportion of crop that can be marketed as first quality (pack-out). While pack-out is directly related to average fruit quality, the visual components of quality, i.e. colour, size and skin finish, predominantly determine whether a premium price is achieved. Fruit quality is the result of a complex interaction of management and environmental factors. By understanding the impact of environment, culture, harvesting, handling and storage on fruit quality, growers should be able to improve both average quality in their crop as well as improving the proportion of fruit in the highest quality grade.

Whilst management practices such as pruning, shading, and crop regulation methods have been widely studied as individual or isolated issues, the role of each in commercial orchard systems is less well understood. From the literature, it was concluded that available information was conflicting in relation to the impact of practices such as pruning and chemical thinning on fruit quality, while the impact of crop load on fruit quality was often confounded by the effect of chemicals used to manage crop load.

The impact of time and level of pruning, protection of fruit from direct sunlight, and crop regulation was studied in a series of field experiments in orchards managed to local commercial standards. An examination of level and time of fruit thinning on a range of cultivars is included along with an assessment of two new generation blossom thinners (desiccants). As these desiccants frequently cause varying degrees of foliar damage, the impact of various levels of simulated foliar damage on both crop load and fruit quality was assessed. The blossom desiccant ammonium thiosulphate (ATS) showed positive effects on fruit quality with an increase in both fruit firmness and sugar content. Potassium thiosulphate showed similar promise to ATS in terms of both fruit quality and as a method of managing crop load. Low levels of foliar damage during the flowering period had little effect on fruit quality but, where 75% or more of the leaf surface was lost, fruit quality was affected and

fruit set was reduced. This study confirmed that loss of leaf area affects fruit quality but it also showed differences between the two cultivars studied.

It has been demonstrated by this study that both the degree and timing of pruning can affect crop load, fruit size, and fruit quality. Pruning during the dormant winter period resulted in better fruit quality than when pruning was delayed until after fruit set. Summer pruning adversely affected fruit size, sugar content and fruit skin finish.

Both crop load and fruit size were reduced by overall shading of trees during early fruit development. Covering individual fruit with commercial paper ‘apple bags’ improved fruit skin finish with the effectiveness related to time of application. The earlier in the season fruit is covered, the more likely that fruit skin damage will be prevented.

Early thinning had a positive effect on fruit quality, resulting in larger, firmer fruit with higher sugar levels. Evidence also showed that early thinning caused fruit to mature earlier than later thinning. In addition, positive relationships were demonstrated between fruit sugar content and weight, between fruit firmness and weight, and between fruit sugar content and fruit firmness. These relationships have not been reported previously and demonstrate that early thinning is a valuable tool in improving fruit quality.

Overall results were consistent with the established view that major aspects of fruit quality are determined in the first few weeks of development when cell division is dependent on carbohydrates derived from storage or limited current photosynthate. This study has demonstrated that by increasing awareness of the impact of orchard management practices on fruit quality and making appropriate adjustments, the base level of fruit pack-out can be increased with minimal or no additional cost to growers.

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Past experience, if not forgotten, is a guide to the future

Chinese Proverb

Publications

1. Papers published

Bound, S A and Wilson, S J (2004) Response of two apple cultivars to potassium thiosulphate as a blossom thinner. *Acta Horticulturae*, **653**, 73-79. (Chapter 7)

Bound, S A and Summers, C R (2001) The effect of pruning level and timing on fruit quality in red 'Fuji' apple. *Acta Horticulturae,* **557**, 295-302. (Chapter 4)

2. Papers submitted

Bound, S A and Wilson, S J (2005) Evaluating the effect of ammonium thiosulphate and 6-benzyladenine on crop load and fruit quality of 'Delicious' apple. Submitted to *Australian Journal of Experimental Agriculture*. (Chapter 7)

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Chapter 1

General Introduction

Apples, along with oranges and bananas, dominate the world market as one of the most popular fruits. World apple production has expanded considerably over the last 10 years, with total production becoming increasingly dominated by China (Hassall & Associates 2001). On a global scale, Australia accounts for less than one percent of world production, but it is ranked sixth in terms of production amongst southern hemisphere producers. In world rankings of overall competitiveness, Australia ranks 12th in production efficiency and 11th overall.

The farm-gate value of the Australian apple industry in 2000 was approximately $266 million (Campbell 2002) with a production of 319,000 tonnes. In 2003 production declined slightly to 314,300 tonnes (ABS 2003). A further 22% decrease in production in 2004 down to 250,300 tonnes reflected unfavourable seasonal conditions, including drought, frost or hailstorms in most states (ABS 2004). However, production is expected to increase over the next few years as new plantings come into bearing age. Production in Australia is centred in distinct regions across all states (Appendix 1). Table 1.1 details production and yields for the 2003 and 2004 seasons as well as the major apple growing regions in each state.

Within Australia, apples are grown predominantly for the fresh apple market, both domestic and export. Processing provides a residual market for undersized and damaged fruit, and fruit not suitable for the fresh market is processed as either juice, canned or dried fruit.

The general level of pack-out for the fresh fruit market in Australia is about 70%, with the processing sector absorbing around 20-30% of the crop (Hassall & Associates 2001). As processing fruit is generally sold near, or even below, the cost of production, the ratio of fresh market to processing fruit has an important bearing on profitability, both at an on-farm level and across the industry. While fruit pack-out is directly related to fruit quality, it is normally the visual quality parameters that determine whether a particular fruit is consigned to the fresh market or for processing. These parameters include fruit size, skin colour and finish, insect/disease damage and bruising. Even within the fresh market grades, factors such as colour and size determine whether a premium price is achieved. Although traditionally the industry has attempted to produce significantly larger, firmer and redder fruit, this approach tends to result in a small percentage of high grade fruit, with the bulk of fruit either standard or processing grade. By concentrating on a base level of quality and working towards achieving a higher percentage of fruit above this base-line, it should be possible to improve both pack-out and consumer acceptance of fruit.

Table 1.1*: Apple production, yield and growing regions for each Australian state.*

State	**Total production* (‘000 tonnes)**		**Yield* (kg/tree)**		**Regions**
	2003[1]	**2004[2]**	**2003[1]**	**2004[2]**	
Victoria	112.4	79.0	44.8	29.3	Bacchus Marsh eastern metropolitan area of Melbourne Gippsland Goulburn Valley Harcourt Mornington Peninsula
New South Wales	61.4	40.7	33.3	23.8	Batlow Bilpin – Camden Forbes Orange
Tasmania	52.4	40.6	41.1	31.4	Huon Valley Spreyton Tamar Valley
Western Australia	35.7	39.0	42.4	41.5	Donnybrook Manjimup Perth Hills
South Australia	28.9	20.3	31.0	18.2	Adelaide Hills
Queensland	23.5	30.7	29.3	31.3	Stanthorpe
ACT	0.1	0.1	22.8	18.9	

*Data sourced from: [1]ABS (2003) and [2]ABS (2004)
Yield represents the quantity of fruit produced per tree of bearing age, i.e. 4 years and over.

Both yield and pack-out are dependent on cultivar and management practices and the interaction of both with the local environment. In commercial practice, management and environmental conditions can result in lower than expected pack-out with fruit downgraded for any of the following reasons:

Environmental factors: sunburn; hail damage; frost damage; prolonged wet and/or cold conditions directly affecting fruit finish (russet); poor drainage influences on tree health; soil fertility and other soil conditions.

Management factors: inappropriate cultivar or rootstock selection for the growing environment; inappropriate planting density, row orientation or planting system; pest and disease damage; crop load management; incorrect water management; weed control and orchard floor management; damage due to spray application.

Harvesting, handling and storage factors: fruit maturity level at harvest; bruising during picking, grading and packing; post harvest dips; storage conditions and length of storage; transport distribution issues.

Hassall & Associates (2001) summarise the importance of quality as follows:

- in the domestic market, quality influences consumer apple purchases relative to other competing products (such as other fruits, snack products and confectionary)
- in the export market quality provides a means of differentiating Australian product from that of major competitors.

While the grower has little control over factors such as climatic conditions, it is possible to influence the impact of many other factors. For instance, by careful selection of cultivars and rootstocks to suit the growing environment, the grower is able to exert some control over localised environmental factors. Cultural practices, maturity at harvest, harvesting method, and post-harvest handling methods can all be managed to optimise fruit quality within a particular environment, and thus maximise fruit pack-outs.

This study concentrates on some of the cultural practices that impact on fruit quality. Whilst fundamental management practices such as pruning, shading (canopy structure), and crop regulation methods have been widely studied as individual or isolated issues in relation to tree and crop growth and development, the role of each in commercial orchard systems is less well understood or documented. The impact of these factors on a system designed to maximise pack-out is studied in terms of time and level of pruning, protection of fruit from direct sunlight and crop regulation. As the latter is the most significant determinant of quality on a season by season basis (i.e. requires adjustment in response to both current and past seasonal conditions) it is examined in more detail than the other issues. Previous work by the author (Bound 2001a; Bound and Jones 1997; 2004; Bound *et al*. 1991a; 1991b; 1993a; 1993b; 1997) has contributed to crop regulation models described by Gillard *et al.* (1997) and Jones *et al*. (1997a; 2000) but the mechanisms and differences between systems and cultivars remain unclear. An examination of level and time of fruit removal during the blossom and early post-bloom period on a range of cultivars is included along with an assessment of some of the new generation blossom thinners. As these frequently cause varying degrees of foliar damage, the impact of various levels of simulated foliar damage on both crop load and fruit quality was assessed.

Chapter 2

Literature review

1. What is fruit quality

Fruit quality is not easily or simply defined – it is a combination of a number of physical and chemical properties, both external and internal, of the fruit. Quality has been described by Génard and Lescourret (2004) as a multi-criteria concept. These authors quoted Arthey (1975) as saying: *the quality of a horticultural product is assessed from the relative values of several characteristics which considered together will determine the acceptability of the product to the buyer and ultimately the consumer*. The meaning of quality varies depending on the perspective of the person discussing it. Kader (1999) outlined the following different perspectives amongst producers, marketers and consumers: *To producers a commodity must have high yield and good appearance, must be easy to harvest, and must withstand long-distance shipping to markets. Appearance quality, firmness and shelf-life are important from the point of view of wholesale and retail marketers. Consumers judge quality of fresh fruits on the basis of appearance (including "freshness") and firmness at the time of initial purchase. Subsequent purchases depend upon the consumer's satisfaction in terms of flavour (eating) quality of the product*. Barritt (2001) confirmed these perspectives.

Factors used to describe fruit quality are considerably more extensive than those listed above, and include: freedom from pesticide residue; size; shape – length/diameter ratio, prominence of crowns, flattening, uneven or lopsided development; skin background colour (green to yellow); colour in red cultivars (% redness); skin finish – freedom from blemishes (russet, wind rub, insect damage, disease) and greasiness; freedom from bruises; flesh texture (firmness, crispness, mealiness); juice content; flavour; acidity; sugar content; flesh firmness; mineral and vitamin content.

Looney (1993) suggested that large fruit size, attractive appearance, characteristic or distinctive flavour, and pleasing texture are amongst the most important fruit quality attributes. In many world markets deficiencies in any one of these key quality attributes can render a product valueless. Retailers and wholesalers consider that there are four main quality problems with apples: immaturity, over-ripeness, poor grading (mixed colour/sizes), and marks and blemishes (Anon 1985).

Two groups of quality components have been identified by Link (2000). Group 1 characteristics include attributes such as size, colour, skin performance, firmness and sugar and acid content of the fruit. Group 2 characteristics were described as being represented by inorganic components, especially calcium and potassium which are implicated in the susceptibility of fruit to physiological disorders. The scope of this study is limited to Group 1 type characteristics.

2. Fruit quality attributes

The first assessment of fruit quality is usually visual, being determined by size, shape, skin colour and freedom from blemishes. Textural quality factors include firmness, crispness, juiciness and mealiness, while flavour or eating quality depends upon sweetness, acidity, astringency and aroma (Kader 2002). Many of these attributes are subjective in nature while others can be measured directly. The attributes examined in the studies presented in this thesis have been restricted to those that can be measured directly with simple equipment and include size, shape, colour, soluble solids content, flesh firmness and starch levels.

2.1: Size

Size differences in fruit are primarily due to differences in the number and individual size of cells within the fruit cortex and pith (Smith 1950; Martin *et al*. 1964; Sugiura *et al*. 1995; Webster 1997). According to Smith (1950), the characteristic size for each cultivar is determined primarily by the degree of cell multiplication occurring after pollination, however he stated that the relation between increase in fruit weight and cell enlargement was not the same for each cultivar.

Cell numbers are determined within the first few weeks of fruit development (Webster 1997). Smith (1950) and Bain and Robertson (1951) reported that cell division in the flesh (pith and cortex) of the fruit stops about 4-6 weeks after blossom. This time period agrees roughly with the findings of Stanley *et al.* (2000), who concluded that a potential maximum fruit size is set by about 50 days after pollination and is determined by total fruit cell number, resulting from a temperature-responsive cell division growth phase. Under ideal conditions, where there are no limiting factors after the cell division phase, all fruit cells would expand to their optimum size to provide the maximum fruit weight achievable for that cell number. They reported that factors limiting carbohydrate availability, such as higher crop loads and shading of trees, reduced final fruit size.

While crop load and the genetic biological carrying capacity (source-sink relationships) determine the potential for fruit size development in apples, the environment within which the fruit grows attenuates this potential (Garriz *et al.* 2000). Genetics, environment and cultural practices all interact to determine eventual fruit size. Of the genetic factors, cultivar plays the dominant role, with rootstock having a smaller more subtle effect (Ferree 2000).

Rom and Barritt (1987) have identified spur age as a factor affecting fruit size, reporting that spurs over four years old produced smaller fruit and Wilton (1989) recommended removal of older spurs by pruning to improve fruit size. Goffinet *et al.* (1996) suggested that a fruit retained at any of the positions within a cluster has a similar potential for achieving the size and weight typically seen in king fruit. Wilton (1997) concluded that fruit bud quality and strength of the wood carrying the buds are more critical than the actual wood age itself, stating that even lateral buds of one year fruit wood will size well if carried on strong wood. Robinson *et al.* (1983) also reported that the age of spur upon which the fruit is borne was much less important than light exposure as a contributor to variation in fruit size and quality.

Jackson (1967) reported that fruit of 'Cox's Orange Pippin' borne on 3 or 4 year old wood were larger than those on younger or older spurs, and that spur age accounted for less than 10% of the total within-tree variation for fruit weight. According to Myers (1990) a prerequisite for creating high spur quality is optimal light, which is achieved by tree training and pruning practices.

Fruit size tends to be smaller on one-year-old wood compared with older spurs (Jackson 1970; Volz *et al.* 1994). In studies of inflorescences on one- and two-year-old wood, Marguery and Sangwan (1993) found that, while cell division began a few days later on the younger wood because of the later blooming time, the mitotic period stopped simultaneously on both ages of wood (40-50 days after full bloom (dAFB) on the 2nd year wood). They concluded that fruits from one-year-old wood were smaller than other fruits because they had fewer cells, probably due to later flower opening and pollination.

Many environmental and tree physiological factors influence fruit cell number and size. The availability of water is of vital importance as this influences cell expansion in the later stages of fruitlet development (Webster 1997). Crop load, time and severity of thinning, tree/soil water relationships, tree vigour, tree nutritional status and stress all impact on number of cells within the fruit and individual cell size, and thus affect final fruit size (Westwood *et al*. 1967; Forshey and Elfving 1977; Faust 1989; Boucher 1995; Tromp 1997; Dris *et al*. 1999; Warrington *et al*. 1999; Stanley *et al*. 2000).

Temperatures within the orchard, at and for several weeks after bloom, may affect cell division and hence cell numbers and fruit size at harvest (Webster 1997). Under high temperature conditions, trees tend to stop producing sugars as a result of shutting down photosynthetic activity and this then impacts on fruit size (Anon 1998). In the later stages of fruit growth this is likely to affect cell expansion.

Several studies have shown a strong positive correlation between temperatures, immediately following bloom, and fruit size at harvest (Jackson and Hamer 1980;

Jackson *et al*. 1983; Lakso *et al*. 1995). In studies with potted apple trees in controlled environments, both Tromp (1997) and Warrington *et al.* (1999) provided further evidence that temperature during early fruit development is a key driver of fruit development. Warrington *et al.* (1999) reported that the duration of cell division appeared to be inversely related to mean temperature (i.e. prolonged under cooler conditions). In their work with several cultivars, mean fruit weight from warm post-bloom (25/15°C) temperature regimes was up to four times greater than from cool post-bloom (9/3°C) temperature regimes. Hence it appears that, while cell division may be prolonged under cooler temperature conditions, this does not compensate for a lower rate of cell division. In addition, their study demonstrated that post-bloom treatments markedly affected fruit maturation, with fruit from warm post-bloom temperature conditions having a higher soluble solids concentration, more yellow background colour, lower flesh firmness, and greater starch hydrolysis than fruit from cooler temperatures. The influence of diurnal variation in temperature during the period directly after anthesis on cell number and size was demonstrated by Atkinson *et al*. (2001). These authors found that trees grown under ambient conditions, i.e. exposed to diurnal temperature variations (18/9°C), produced fruit with smaller cells and greater cell numbers than fruit grown at a constant temperature of 15 or 20°C. They also reported that while higher temperatures produced larger fruit, increasing the temperature induced larger, not more, cells per fruit.

Warrington *et al.* (1999) suggested that the impacts of temperature on apple fruit growth are further complicated by varying responsiveness to temperature at different phases of growth. In order to maximise yield, it is important to know the phases of growth that are most susceptible to environmental manipulation (Schechter *et al.* 1993). Both Magein (1989) and Schechter *et al.* (1993) suggested that the growing season can be divided into three phases: phase one, beginning at bloom and lasting about 40 days, corresponds to the period of maximum fruit growth rate and is dominated by cell division; phase two is characterised by a considerable reduction in growth rate – this stage never exceeds 2 weeks; and phase three is the period of the largest volumetric growth rate and spreads over the rest of the season. According to Baumann and Henze (1983), the development of fruits during the third phase results mainly from the enlargement of cortex and pith cells, and from the increasing volume of intercellular spaces.

There is, however, some disagreement about this triphasic model and other researchers have described different patterns of growth in apple. According to Blanpied and Wilde (1968) the apple fruit grows in two distinct phases: an early exponential phase of cell division that typically lasts for ~35-45 days after anthesis, followed by a cell expansion phase for the remainder of the season. This overall growth pattern has been described using expolinear modelling (Lakso *et al*. 1995).

Schechter *et al*. (1993) suggested that the end of phase one is associated with the end of canopy development and shoot terminal bud formation, and coincides with the 'June' drop ('December' drop in the southern hemisphere), reducing the number of photo-assimilate-consuming fruits while carbohydrate export capability of shoots is maximised. However after describing three phases of growth, Magein (1989) concluded that 'June' drop is not directly connected with the intensity of fruit growth rate reduction.

In Australia, Bain and Robertson (1951) found that large apples had more cells than small fruit from the same tree but there was no difference in cell size. Westwood *et al.* (1967) reported that heavy hand thinning resulted in larger king fruits with larger cells than lateral bloom fruits which had the same leaf:fruit ratios, however they could not explain the difference in cell size between king and lateral fruits on the basis of leaf:fruit ratio. The difference in fruit size between trees bearing light and heavy crops has been found to be due to cell size rather than cell number (Martin and Lewis 1952). Smith (1950) related year to year variation in fruit size to both cell size and cell number.

Factors which tend to increase cell size include: few cells per fruit, adequate soil moisture, king fruits (position in cluster), excess nitrogen fertiliser, high leaf:fruit ratio, late-season thinning, healthy leaves, excessive chemical thinning (Westwood *et al*. 1967).

Factors affecting cell number and cell size of fruit have economic importance because, as well as determining fruit size, they can impact on storage behaviour. Martin and Lewis (1952) found that apples with larger cells were more susceptible to storage disorders than those with smaller cells. In New Zealand, Letham (1961) found a relationship between cell size and breakdown in 'Sturmer', and showed that fertilising with nitrogen tended to decrease the number of cells per fruit, thereby leading to an increase in cell size. Martin *et al.* (1964) suggests that the desired commercial aim of producing larger fruits of good storage capacity might best be achieved by keeping cell size to a minimum, which implies increasing cell numbers as much as possible.

Seed number has also been shown to have a direct influence on fruit size (Williams 1977; Bramlage *et al*. 1990). According to Williams (1986), at least seven seeds per fruit are necessary for maximum fruit size. Brookfield *et al*. (1996) related the number of seeds per fruit to pollination, reporting that seed number was lower in fruit without a nearby pollen source. Hand pollination of trees away from the pollen source restored full seed number.

2.2: Shape

Fruit shape in apples is controlled by both climatic and non-climatic factors (Veinbrandts 1978). Seeds also influence fruit shape, with the absence of seeds in carpels resulting in asymmetric fruit development (Childers 1976; Brookfield *et al*. 1996; Dražeta *et al*. 2004).

Other factors such as rootstock, cultivar, crop density and position of the fruitlet in the cluster also tend to influence fruit shape. The interaction of these factors in combination with environmental conditions determines the *typiness* of 'Delicious' apples in particular, under orchard conditions. For strains within this cultivar, the expression *typiness* describes the development and prominence of the calyx lobes of the fruit. Usually fruit with poor development of these lobes are flatter than those with well developed lobes.

In the early 1900's Shaw (1914 [cited in Noè and Eccher 1996]) observed that fruits became elongated when the period after bloom was cool. Cool temperatures during the cell division and early developmental period cause fruits to elongate, whereas warm temperatures tend to produce oblate flattened fruits (Westwood and Burkhart 1968; Williams and Stahly 1969). McKenzie (1971) reported that fruit from the mild, moist conditions of the northern regions of New Zealand were flatter than those from the cooler drier climate of the south. Eccher (1986) observed that 'Golden Delicious' fruit grown at higher elevations in Italy were elongated and had smoother skins than those from low valleys which were shorter and often russeted. Day/night temperature differences, air and soil temperatures, and relative humidity have also been shown to affect fruit shape (Sullivan 1965; Greenhalgh and Godley 1976; Tromp 1990). Noè and Eccher (1996) reported that fruit shape was affected by light treatment, with shading by corrugated fibreglass sheets to cut off UV-B and violet wavelengths resulting in more elongated fruit. However, in their work, as well as cutting off irradiance between 300 and 400 nm (UV-B and violet), the irradiance of the rest of the spectrum was reduced by 15%. While Noè and Eccher did not discuss this issue, it is likely that this reduced light intensity also influenced fruit shape.

Although both inherited (Westwood and Blayney 1963) and environmental factors (Greenhalgh and Godley 1976) play a major role in fruit typiness, application of synthetic hormones can also have an important and immediate impact. Localised application of gibberellins (GA) can induce asymmetric growth of apples as a result of tissue enlargement (Bukovac and Nakagawa 1968). Dennis and Nitsch (1966) and Hayashi *et al.* (1968) demonstrated that gibberellins promoted cell elongation and division in apples. There has been considerable discussion on the ability of gibberellin and cytokinin mixtures to increase the length of apples and make them more typy (Williams and Stahly 1969; Stembridge and Morrell 1972; Veinbrandts 1978; Looney 1979; Curry and Williams 1983; Greene 1993a).

Greenhalgh *et al*. (1977) found that in both New South Wales and Western Australia, typiness of 'Delicious' apples can be improved by the use of blossom applications of GA_{4+7} and 6-benzyladenine (BA), stimulating an increase in the length/diameter (L/D) ratio of the fruit and development of the calyx lobes. While their findings confirmed that both GA and BA influence the development of form and shape in 'Delicious' apple they found that sprays combining GA_{4+7} and BA in equal proportions provided little additional benefit to that obtained with BA alone at the equivalent strength. Jones (1979) improved fruit typiness and increased the length of fruit, without increasing the width, with full bloom (FB) applications of Promalin® (a 50:50 proprietary formulation of GA_{4+7} and BA in a 2% solution, Abbott Laboratories). In trials over two seasons Veinbrandts (1978) demonstrated that Promalin applied to runoff as a single spray shortly after FB improved fruit shape by increasing the L/D ratio. In addition Promalin improved the prominence of the calyx lobes equally at all concentrations. In Australia the plant growth regulator Cytolin® (registered as Promalin in the USA) is commonly used to elongate and improve the shape of 'Delicious' (Veinbrandts and Miller 1981; Miller 1985; Bound *et al*. 1991a; 1993a).

2.3: Colour

Skin colour has two components – background colour and red colour (or blush in green cultivars). Background colour is used as an index of maturity, with a subjective estimate of the change from mainly green colour on unripe apples to the more yellow tones on ripe apples (Australian Horticultural Corporation 1993) specified as a measure of fruit maturity. Red colour is not regarded as a reliable indicator of maturity, but is normally taken as a quality factor unlikely to change substantially as fruit progresses through the last stages of development. Fruit is picked either when the red colour meets a grade standard, as for 'Delicious', or when red colour is sufficient and background colour indicates that an appropriate level of maturity has been reached. Poorly coloured fruit is usually downgraded from fresh market to processing grade or left on the tree.

The extent and intensity of colour in red cultivars is affected by many climatic and cultural factors (Saure 1990), with poor red colour limiting the pack-out of first grade fruit. Weather conditions have been reported by several authors to impact on fruit skin colour (Chandler and Mason 1942; Simons 1959; Tukey 1960; van Zyl 1970; Hatch 1975; Simons and Chu 1978; Creasy 1980; Creasy and Swartz 1981; Saure 1990; Meheriuk *et al*. 1994). There also appear to be differences in colouring ability between cultivars. Kikuchi *et al*. (1997) stated that 'Fuji' apples require a higher intensity of light than other cultivars to produce the same amount of anthocyanin (red colour pigment). Marsh *et al*. (1996) found that red colour tends to be poor in younger trees, with a general improvement in the fruit colour profile with tree age. Increased red colour can be accomplished by (1) selection of sports or mutations, (2) bagging fruit, and (3) management practices such as irrigation, fertilisation, pruning and thinning (Kikuchi *et al*. 1997).

Higher nitrogen concentrations have been correlated with lower red colour in 'McIntosh' apples (Boynton and Cain 1943). Boucher (1995) reported that high leaf levels rather than high fruit levels of nitrogen are associated with poor colour, suggesting an indirect rather than a direct effect of nitrogen on skin colour. A survey conducted by Marsh *et al*. (1996) in New Zealand confirmed that tree vigour, tree nitrogen status, and growing region are important factors determining the extent and intensity of red colour development in 'Fuji' apple. They reported that increased vigour generally results in a decline in the extent of red colour development, the result of an indirect effect caused by shading. This supports the conclusions of Weeks *et al*. (1958).

2.4: Skin Finish

Problems with fruit skin finish can be divided into blemishes or skin damage. A blemish is defined as any superficial disfigurement of the skin that is not likely to affect the keeping quality of the apple. Blemishes include russet and healed injuries caused by limb rub, insect damage, abrasions and scratches. Skin damage is any unhealed physical injury to the surface of the apple, and includes bruising and any injury that leaves the skin broken and unhealed such as stem punctures or recent hail damage (Australian Horticultural Corporation 1993).

Fruit skin russet is a natural phenomenon, occurring when the cuticle, or waxy outer portion of the skin, is damaged. This can be caused by either outside forces such as frost, chemical or disease damage, or by internal forces such as rapid epidermal growth, which cause the protective cuticle to rupture (Faust and Shear 1972; Curry 1991; Alder 1994). In both cases, a layer of cork cambium develops, pushes outward and replaces the cuticle as the outer protective layer of the fruit. Unlike the smooth waxy cuticle, cork cambium is rough in texture and gives the fruit a russeted, scabby appearance. Curry (1991) suggested that this occurs in the early weeks after anthesis, when fruit is most susceptible to damage.

Whilst russet does not affect taste or other quality parameters it does have an affect on the visual appeal of the fruit and hence a serious detrimental effect on market value. For russet susceptible cultivars it constitutes a major problem. In the short term it causes immediate financial loss to the producer, and over the long term it could lead to consumer resistance (Steenkamp *et al*. 1984). In the case of ‘Fuji’ grown in Tasmania, russet can result in more than 50% of otherwise suitable fruit being rejected from the profitable export market to the less profitable domestic consumption (Boucher, personal communication).

Zschokke first described russet in the literature over a century ago in 1897 (Faust and Shear 1972). Since then numerous factors have been linked with russet on apples. Cultivar has been reported to influence skin finish (Chandler and Mason 1942; Skene 1982). Steenkamp *et al*. (1984) suggested that the sensitivity of a cultivar and the intensity of russeting depend on the nature and composition of the wax layer, which in turn could be influenced by external environmental factors. During the first six weeks of fruit development the fruit surface is subject to rapid growth and is therefore under severe tension (Wertheim 1982).

It is well established that cold or wet conditions can increase the incidence of russet (Creasy 1980). High humidity, precipitation and frost have also been associated with increases in the disorder (Chandler and Mason 1942; Simons 1959; Tukey 1960; van Zyl 1970; Hatch 1975; Simons and Chu 1978; Creasy 1980; Creasy and Swartz 1981; Meheriuk *et al*. 1994), as have altitude and light (Damas 1989; Looney *et al*. 1992a; Eccher and Noè 1993; Noè and Eccher 1996).

Chemical sprays such as ethephon (Jones *et al*. 1991a), captofol fungicide (3a,4,7,7a-Tetrahydro-2-[1,1,2,2-tetrachloroethyl)thio]-1H-isoindole-1,3(2H)-dione) (Gupta 1983), and copper fungicide sprays (Slade 1979; Wundermann 1981; Jones *et al*. 1994) have been implicated in russet development. Other chemicals that have been reported to induce russet include: urea (Stiles *et al*. 1959), dodine (*n*-dodecylguanidine acetate) (Kirby and Bennett 1967; Hatch 1975), fungicides based on dimethyldithiocarbamyl compounds (Kirby *et al*. 1970), daminozide (butanedioic acid mono-[2,2-dimethylhydrazide]) (Creasy and Swartz 1981), thiram (Bünemann 1982) and the non-ionic surfactants Citowett and Tween 20 (Noga and Bukovac 1986). Boucher (1995) reported that any chemical spray applied under the wrong weather conditions during the critical fruit development period from pink bud to 6 weeks after full bloom (wAFB) is capable of causing russet.

As it is difficult to control all of the environmental conditions likely to induce russet under commercial conditions, many researchers have attempted to manipulate fruit growth with hormones in an attempt to overcome the formation of cracks in the wax layer caused by environmental factors. Attempts to reduce russet have mainly centred on the use of GA_{4+7} (Taylor 1975; Wertheim 1982; Meador and Taylor 1987; Steenkamp and Westraad 1988; Looney *et al.* 1992a; 1992b; Bubàn *et al.* 1993; Greene 1993a). However, other practices that have reduced russet include spraying sulphur compounds (Drozdovkiî *et al.* 1993), bagging fruit (Creasy and Swartz 1981; Warner 1995), and changing light regimes (Eccher and Noè 1993). In studies with different light spectrums Noè and Eccher (1996) concluded that modifications of light quality by shading and/or supplementary lighting during natural daylight with ultraviolet and infrared lamps reduced russeting. However they were unable to clarify which wavebands were involved or how light quality reduced russet.

2.5: Starch content

Starch changes to sugar as the apple ripens, with starch hydrolysis beginning in the core area and progressing outwards. Starch is one of the standard measures of fruit maturity (Little 1999; Chennell *et al*. 2002), with starch levels declining rapidly from about the start of the respiratory climactic. According to Little (1999), the hydrolysis of starch corresponds reasonably well with increasing ethylene status within apples during the harvest period. Starch is not regarded as a quality component in its own right, but is used in conjunction with other maturity indicators.

2.6: Total soluble solids content

As noted previously, starch converts to sugar as the apple matures. Once the ripening phase starts, starch levels decline and sugar levels increase rapidly. Total soluble solids (TSS) content, 98.8% of which are sugars (Little 1999), is another standard index of fruit maturity.

According to Kupferman (2002), sugar levels depend on the leaf to fruit ratio, hence anything that increases leaf size and optimises photosynthesis throughout the canopy will aid in accumulation of sugar in the fruit. Collins (2003) suggested that sugar content can be influenced by a range of factors such as irrigation, nutrition, weather and position on the tree. Eccher and Noè (1993) have reported that the altitude at which apples are grown influences sugar content. However it is difficult to see how these authors could have maintained the same environmental and management conditions at different altitudes to allow them to separate altitude from other factors associated with altered sugar levels.

2.7: Flesh firmness

Fruit flesh firmness, usually measured as the resistance of the apple flesh to penetration using a penetrometer (with an 11 mm plunger), is another indicator of maturity. A gradual decrease in flesh firmness occurs as the apple reaches full size and starts to mature (Little 1999), but according to Westwood (1993), flesh firmness is not a good index for early harvest of apples because it does not relate well to maturity. However, this author suggested that firmness tests have value for later harvest and during storage, particularly when used with other indices. Apples less than 5.5 kg firmness at the point of sale are considered to be lacking in firmness and not acceptable to the average consumer (Australian Horticultural Corporation 1993).

Firmness is related to both the size and number of cells within the fruit. Large cell size generally means softer fruit (Jones *et al.* 1998). Firmer fruit can be achieved by increasing cell numbers while keeping cell size to a minimum (Martin *et al*. 1964). Seasonal and orchard variability, tree vigour, fruit size, nitrogen and calcium levels in the fruit and use of growth regulators are some of the things known to influence firmness of apples (Little 1999). Following observations that fruit firmness was higher on older spurs, Robinson *et al.* (1983) suggested that this increase in fruit firmness with increasing spur age was a result of the decrease in fruit size associated with increased spur age or delayed maturity.

3. Factors affecting fruit quality

Fruit quality can be influenced by both pre- and post-harvest factors. Some of these become fixed once the orchard is established and cannot be controlled after planting, while others are variable and can be influenced by management and cultural choices made by the grower. Fixed pre-harvest factors include: the genetic component (cultivar/selection and rootstock); orchard factors such as site, planting density, tree training system, tree age, virus load and soil type; and environmental factors (light, temperature, rainfall, humidity). Cultural factors, including irrigation, pesticides/adjuvants used in the spray program, nutrition, pruning, crop load management and orchard floor management, are all variable factors.

This study will be limited to the impact of variable orchard management factors such as pruning, artificial shading, covering of fruit and crop load management on fruit quality.

3.1: Pruning

The vegetative wood in a tree competes with fruit for carbohydrates, and young fruit are known to be weak sinks, with both fruit set and size decreased by competition from vegetative shoots (Quinlan and Preston 1971; Jackson and Palmer 1977a; 1977b; George *et al*. 1996) and from other fruit (Lakso *et al*. 1995). According to Quinlan and Preston (1971), removal of whole shoots or shoot tips during the early part of the season increases fruit set. The ultimate aim of pruning is to manipulate tree growth and size.

Timing and method of pruning

There is considerable variation in the timing and method of pruning used by different authors (Dietz 1984; Morgan *et al.* 1984; Taylor and Ferree 1984; Scholtens 1992; Ystaas *et al.* 1992; Katzler and Wurm 1998). Some authors have described the effects of pruning in summer without previous dormant pruning (Dietz 1984; Taylor and Ferree 1984; Ystaas 1989, Ystaas *et al.* 1992), while others such as Morgan *et al.* (1984) and Scholtens (1992) imposed summer pruning on trees that had previously been dormant pruned. In addition, there may be differences in the type of pruning undertaken at the different pruning times. For instance, Taylor and Ferree (1984) used thinning out cuts in their dormant pruning, but in the summer treatments, headed all shoots longer than 10cm.

Dormant pruning

Dormant pruning restricts growth of roots and reduces the trunk circumference increase of a tree, but growth is stimulated near the pruning cut (Elfving and Forshey

1976). As pruning practices can influence both light distribution and age of bearing wood, Robinson *et al*. (1983) suggested that knowledge of the influence of spur age on fruiting and fruit quality is important.

In 'Golden Delicious', Uitterlinden and Westerlaken (1970) found that light pruning resulted in considerably more fruit skin russeting than did hard pruning. Work by Bound and Jotic (1995) on ‘Fuji’ also demonstrated that fruit from trees hard pruned during winter dormancy had lower russet levels than that from lightly pruned trees. One hypothesis to explain this is that lightly pruned trees are denser, thus reducing air movement in the tree, resulting in slower drying of fruit after damp/wet conditions.

Katzler and Wurm (1998) reported that the highest quality fruits, based on organoleptic scores, were produced following severe winter pruning. However, reports on the influence of level of pruning during the dormant period on internal fruit quality parameters such as fruit firmness and soluble solids content are lacking.

Summer pruning

There are conflicting reports of the influence of summer pruning on fruit quality (Perring and Preston 1974; Terblanche and Pienaar 1977; Utermark 1977; Lord and Greene 1982; Marini and Barden 1982; Katzler and Wurm 1998). Crassweller (1999) defined summer pruning as the removal of any vegetative growth when there are leaves or flowers on the tree. The definition included de-suckering the tree interior, selecting scaffolds on young trees, tipping terminal growth, or dormant style pruning conducted during the growing season. If responses to summer pruning are dependent upon the time of year pruning is done, the type of pruning cut, location, tree vigour, and previous history as mentioned above, variations in published reports may be explained.

Miller (1982) found no effect of summer pruning on the size of 'Delicious' fruit, but Taylor and Ferree (1984) reported a reduction in fruit size with summer pruning in some seasons. Marini and Barden (1982) and Myers and Ferree (1983) also reported that summer pruning reduced fruit size. However, Dietz (1984) reported that fruit size can be improved by pruning in summer. Morgan *et al.* (1984) reduced the size of 'Gala' fruit with early, but not late, season summer pruning. Katzler and Wurm (1998) found that summer pruning with no dormant pruning reduced fruit size in ‘Jonagold’. Autio and Greene (1990) reported that summer pruning had no effect on fruit weight of 'McIntosh', agreeing with the work of Scholtens (1992) who reported no effect on fruit weight of 'Jonagold' from either early or late summer pruning following winter pruning. According to Stebbins (1989) summer pruning removes some of the leaves needed for sizing and tends to restrict size development.

Summer pruning is often undertaken to improve fruit colour (Dietz 1984; Autio and Greene 1990). Taylor and Ferree (1984) also found fruit soluble solids content reduced with summer pruning but flesh firmness was unaffected. Dietz (1984) reported that sugar and acid contents improved with pruning in summer. However, Ystaas (1989) and Ystaas *et al.* (1992) found reduced TSS content of 'Summerred' fruit following pruning in late summer. This is supported by Katzler and Wurm (1998) who reported that pruning in summer (no dormant pruning) reduced the accumulation of assimilates in fruits.

Lord and Greene (1982) saw no influence of late summer pruning on 'McIntosh' fruit size, soluble solids content, flesh firmness, fruit flesh calcium or senescent breakdown during storage. Studying the cultivars 'Cortland' and ‘Delicious', Greene and Lord (1983) reported that fruit set, yield, flesh firmness, flesh calcium and storage disorders were unaffected in either cultivar. However, they did report a reduction in fruit size and soluble solids content in 'Cortland' but not 'Delicious'. They concluded that differences in fruit size and soluble solids content between the two cultivars could be explained largely by the type and severity of pruning procedures – in 'Delicious' the number of leaves in close proximity to the fruit were not reduced by summer pruning, whereas in 'Cortland' there was a substantial reduction. Lord and Greene (1982) suggested that the magnitude of fruit quality responses to summer pruning depended on the amount of leaf surface removed and tree vigour. In reporting a consistent decrease in soluble solids content in 'Stayman' following summer pruning, Marini and Barden (1982) emphasised the importance of adjacent leaves as a major contributor to the soluble solids content of apples.

3.2: Light management

The light microclimate within apple trees influences the proportion of total fruit yield classified as high quality and shading due to excessive vegetative growth indirectly affects fruit quality. Adequate distribution of light within a canopy is an important determinant for total yield and aspects of fruit quality such as size and colour (Wagenmakers and Callesen 1995). Jackson (1968) reported that shading results in reduced fruit size, weight and red colour. Autio and Greene (1990) suggested that, if red colour is reduced by shading to a level where grade is lowered, production costs may actually exceed income from the sale of fruit.

In 'Delicious' apple, shading has been shown to reduce yield, red fruit colour, soluble solids concentration, starch content, and fruit length, width and weight (Doud and Ferree 1980; Seeley *et al*. 1980; Robinson *et al*. 1983). Webster and Crowe (1971) also reported that shading altered fruit shape of 'McIntosh' apple, with apples located on wood exposed to sunlight being less elongate than those developing on shaded wood. Sansavini *et al.* (1981) found fruit firmness to be negatively correlated with light levels. This was supported by Robinson *et al.* (1983) who found apple fruit firmness and total acidity were increased by reduced light levels produced through shading. Tree row orientation can also influence fruit quality, with lower yields and poorer fruit quality on the south side of trees in Australia, while the more exposed northern side tends to be more prone to sunburn (Middleton, personal communication).

Jackson and Palmer (1977a; 1977b) have described the adverse effect of shading on fruit size, suggesting that reduced size is due to effects on both cell division and cell size. The only way to obtain large fruit under shaded conditions, such as that found under netting, is to reduce fruit number so that cropping is in balance with the reduced resources (Jackson and Palmer 1977b). Wagenmakers and Callesen (1995) reported that production was proportional to light interception and increased with increasing planting density from 2000-4000 trees per ha, but the amount of well-coloured fruit was the same for all planting densities.

According to Jackson and Palmer (1977a; 1977b) shade influences fruit initiation, and reduces fruit retention, fruit size and percentage dry matter. They also found a residual adverse influence of the percentage flowers that set fruit the following year. Jackson and Palmer (1977b) concluded that the most probable result of management systems or environmental conditions, which impose inadequate illumination, is biennial cropping combined with a low overall yield.

Specialised production systems that shade fruit but not leaves, such as enclosing apple fruit in bags during development as widely practiced in Japan, can have a marked effect on fruit quality. While bags create a physical barrier that reduces damage from insect and fungal pathogens, sprays, sunburn and russeting, there also appears to be a physiological effect on fruit development. Mattheis *et al.* (1996) reported reduced soluble solids content, titratable acidity and firmness at harvest and during storage following bagging of 'Fuji' fruit. Working with *Vitis vinifera*, Shabala and Wilson (2001) have demonstrated that the quality of light directly incident on fruit influences potassium, calcium and proton fluxes in mature fruit tissue.

3.3: Crop load

The single most important factor influencing final fruit size is the crop loading on the tree. Excessive numbers of fruits (ie. very high fruit:leaf ratios) cannot be sized adequately, even with copious irrigation (Webster 1997). The only reliable solution is to reduce the crop loading by:

- reducing blossom numbers by winter pruning or by inhibiting flowering
- preventing a proportion of the blossoms from setting fruit (blossom thinning), either by hand or mechanical methods or by using chemical sprays

- removing a proportion of the fruitlets (fruitlet thinning), by hand, or with chemical sprays.

The time at which crop load is reduced plays a role in final fruit size and quality. Goffinet *et al.* (1995) reported that fruit from 'Empire' trees thinned near bloom were larger with more cells than those of trees thinned later. They suggested that fruit thinning appeared to increase fruit size by allowing remaining fruits to continue cell division under less competition during the first weeks after bloom, and not by extending the cell division period, increasing cell size or increasing the proportion of intercellular space. This confirmed the findings of Martin *et al.* (1964) and Westwood *et al.* (1967) that thinning at blossom time before the major period of cell division produces a much greater increase in cell number than thinning after this period.

Thinning has been shown to increase leaf:fruit ratio (Forshey and Elfving 1977; Myers 1990). Fallahi and Simons (1996) suggested that trees with low yield had a higher leaf:fruit ratio which led to a higher accumulation of photosynthates in the fruit, thus increasing the fruit weight. However Palmer *et al.* (1997) reported that leaf assimilation rate was curvilinearly related to crop load in ‘Braeburn’/M26. These authors found little increase in leaf assimilation beyond a crop load of 12 fruit per m^2 leaf area. A similar effect was observed by Palmer (1992) in ‘Crispin’/M27 with leaf assimilation rate increasing with increasing sink strength towards a saturation point of 10 fruit per m^2 leaf area. Palmer *et al*. (1997) warned that, although they observed a significant response of leaf assimilation to crop load, care must be taken in extrapolating from single leaf responses to whole canopy assimilation.

Investigating the effects of time and level of hand thinning for 'Royal Gala' and 'Braeburn' apple trees growing on dwarfing rootstocks, McArtney *et al.* (1996) found that mean fruit weight of 'Royal Gala' was reduced by 16% when thinning was delayed by 3-4 weeks after full bloom. They concluded that thinning at flowering was desirable, particularly in cool regions and for small fruited cultivars. The effects of temperature and development stage on fruit size have been discussed previously (Section 2.1). Jones *et al.* (1992b) also concluded that it is preferable to thin at blossom time.

Hence the potential size of a given fruit is determined early in the season and growth proceeds at a relatively uniform rate thereafter. As stated by Tukey (1970 [cited in Forshey and Elfving 1977]) thinning does not change a potentially small fruit into a large fruit, but rather ensures that a potentially large fruit will size properly. Forshey and Elfving (1977) recommended that fruit thinning should be limited to the minimum that ensures acceptable fruit quality and adequate return bloom for a full crop. They suggested that large fruits should not be the primary objective because they may be attainable only through over-thinning that may, in turn, stimulate vegetative growth. There is a delicate balance between cropping and vegetative growth in apple trees, with vigorous growth having a negative influence on fruit quality. Fruit quality on trees with excessive vegetative growth is frequently poor, and the storage potential of these fruit is generally diminished (Forshey *et al.* 1992 [cited in Greene 1999]). According to Jones *et al.* (1998), calcium related fruit disorders are particularly prevalent in vigorous trees, and it is difficult to produce quality fruit from strongly growing trees.

In addition to influencing fruit weight and size, crop load can have a major impact on other fruit quality parameters. Johnson (1992) reported that, as well as being larger, fruits from hand thinned trees were less dense and contained less calcium and more potassium than those from unthinned trees, and that thinning tended to increase susceptibility to physiological storage disorders. Hansen (1997) reported that lightly cropped ‘Braeburn’ trees show an increase in fruit quality problems such as bitter pit, lenticel blotching, watercore, soft scald and ‘Braeburn’ browning disorder. However, Garriz *et al.* (2000) found fruit flesh firmness was significantly lower in 'Braeburn' trees carrying high crop loads than in trees with moderate or low crop loads. This finding conflicts with that of Johnson (1992) described above.

In addition to improving the quality of the current crop, fruit thinning also affects the succeeding crop. The following seasons flower buds are formed early in the development of the current crop. These two processes, however, are competitive, and an excessive fruit set inhibits flower bud formation (Forshey 1976). Although the need for thinning varies between regions, in order to crop pome fruit trees consistently every year, in general over 90% of the flowers/fruitlets need to be removed from the tree within six weeks of flowering (Lombard 1982; Jones *et al.* 1998). As well as improving fruit size and quality, early thinning prevents biennial bearing and reduces limb damage caused by heavy crops. While fruit removal by hand can improve fruit size if carried out early enough, hand thinning is expensive and impractical during flowering and the early fruit development stage. Hence hand thinning is normally carried out after flower initiation has taken place, and as a consequence flower formation for the next year is inhibited by the high number of young fruitlets present on trees during flower initiation. This late thinning results in reduced fruit size and quality and the trees tend towards biennial bearing (Jones *et al.* 1998).

3.4: Chemical thinning

Application of chemicals for the purpose of removing excess flowers and/or fruitlets can impact on fruit size, appearance and internal fruit quality either by direct effects on fruit growth and development or indirectly through crop load, tree vigour, and canopy architecture. In commercial orchards, chemical thinning agents are applied either during the blossom period and/or up to 5-6 weeks after flowering (Jones *et al*. 1998). In particular, blossom or fruitlet thinning early in the season improves fruit size at harvest and increases return bloom, thereby reducing the biennial bearing habit of apple trees. As discussed previously, severity and timing of flower or fruitlet thinning can influence final fruit numbers, size and return bloom (Quinlan and Preston 1968; Williams 1979; Looney 1986; Johnson 1992; 1994; Jones *et al.* 1992b; Jones *et al*. 1998). In general, the earlier thinning is performed, regardless of the method, the larger the fruit size at harvest. However, there are some situations where chemical thinning can result in no size benefit at harvest – this can arise where chemicals such as NAA cause a 'check' to vegetative, and thus fruitlet, growth under some circumstances, or where blossom thinners remove the earlier opening flowers, leaving only weaker flowers which have a reduced potential to set large fruit.

Although early thinning has been shown to increase cell numbers and consequently fruit size, the choice of thinning chemical can have an impact on fruit cell numbers. Martin *et al.* (1964) described an increase in cell numbers following the application of dinitro ortho cresol (DNOC) as a blossom thinner at FB. However they found continued thinning and crop reduction following weekly applications of naphthalene acetic acid (NAA) from FB to 3 wAFB, over a period of six years did not increase cell division or fruit growth. Abbott (1954 [cited in Martin *et al.* 1964]) found that NAA inhibits the transport of reserves to the fruit. Wismer *et al.* (1995) showed that BA stimulated cortical cell division, however NAA and carbaryl (1-naphthyl-N-methylcarbamate) applied 14 dAFB had no effect on cell division rate. The fruit size increase in carbaryl and NAA treated fruit was shown to be a consequence of larger cell size. While application timing of a chemical can influence its efficacy (Jones *et al*. 1998), the differences in fruit size effects reported by Martin *et al*. (1964) and Wismer *et al*. (1995) following thinning with NAA are more likely to have been influenced by application rates. Wismer *et al*. (1995) applied one spray of 15 ppm NAA, while Martin *et al*. (1964) applied four sprays of 20 ppm in the first 2 years of their work, 10 ppm in the second 2 years, and 5 ppm in the final 2 years. Differences in experimental protocols between research reports can lead to difficulty in making comparisons between results by different authors and in drawing conclusions.

In terms of fruit size, the effectiveness of a thinning agent can be evaluated and explained in terms of either the number of cells of the cortex tissue or their volume, or both (Costa *et al.* 2000). Wismer *et al.* (1995) found that fruit set and yield were similar for BA, NAA and carbaryl treated fruit, but BA treated fruit were larger. Cell size in BA treated fruit was similar to the control. They concluded that, whereas BA increased the rate of cell layer formation in the fruit cortex, the fruit size increase due to NAA or carbaryl is a consequence of larger cell size. Large apples composed of more numerous smaller cells may be capable of maintaining equivalent or superior quality in long term storage and after storage when compared to apples whose large size is solely a result of increases in cell size.

The chemical thinner carbaryl is known to remove smaller fruit within clusters (Looney and Knight 1985; Knight 1986). However, other chemical thinners such as NAA (Southwick and Weeks 1949) and BA (Greene *et al*. 1992) are not so selective within the fruiting cluster, tending to remove whole clusters, consequently significant proportions of multi-fruited clusters may contribute to the whole crop. Volz and Ferguson (1999) reported that within cluster thinning of 'Braeburn' and 'Fiesta' apple trees around bloom greatly increased fruit size while thinning alternate clusters only slightly increased fruit size.

Although increased thinning normally results in larger fruit, there is evidence to suggest that some thinners depress fruit growth, inhibiting achievement of optimum fruit weight. Both Link (1967) and Wertheim (1974) expressed concern about the use of high concentrations of ethephon or NAA reducing fruit growth while Flore (1978) reported that high concentrations of NAA reduced fruit size. The lack of size response of ‘Golden Delicious’ to higher levels of NAA treatment has also been described by Jones *et al.* (1988). Bound *et al*. (1991a) concluded that application timing of NAA is important after observing no increase in fruit size of ‘Delicious’ following over-thinning with 8 ppm NAA applied 10 dAFB. These authors recommended that NAA be applied no later than 7 dAFB. Schneider and Lasheen (1973), Schumacher *et al*. (1978), Jones *et al*. (1989) and Micke *et al*. (1990) have all demonstrated that NAA used as a thinner can adversely affect fruit growth. Way (1971), Knight (1980) and Jones *et al.* (1983) showed that trees thinned with ethephon can fail to achieve the fruit size expected at effective levels of thinning. Ebert and Bender (1986) suggested that ethephon inhibits fruit growth, however

Jones *et al*. (1993) concluded that it was later applications that impeded growth, not early sprays. However, the post-bloom thinner BA has a positive effect, increasing fruit size independently of the thinning effect (Greene 1993b).

Other fruit quality attributes that may be affected by thinning chemicals include fruit shape, skin finish, sugar content, flesh firmness, or seed number. These effects may be beneficial, resulting in improvements to fruit quality, or they may be adverse. Ethephon has a tendency to flatten fruit, making them less true to type (Bound *et al.* 1993a). Bound and Jones (1997) have also described the fruit flattening effect of the desiccant endothal (dipotassium 7,oxabicyclo (2,2,1) heptane-2-3 dicarboxylate) which has recently been assessed as a blossom thinner.

In Eastern Washington, the recommended application time of 7-14 dAFB for naphthalene acetamide (NAD) can cause abnormally small (pygmy) fruit in 'Delicious' (Anon 1988). Williams and Edgerton (1981) have recommended that ‘Delicious’ not be thinned with NAD in north-western United States because of pygmy fruit formation. In Australia, Bound *et al.* (1991a) demonstrated that application of NAA at or after 10 dAFB resulted in unacceptable levels of pygmy fruit in ‘Delicious’. This confirmed the finding of Miller (1985) after application of NAA at 15 dAFB. Jones *et al*. (1989) also reported that late sprays of 15 ppm NAA applied 14 dAFB produced small fruit in ‘Fuji’. Greene and Autio (1994) reported that a combination of BA and NAA applied 17 dAFB on Starkrimson ‘Delicious’ and 21 dAFB on Redspur ‘Delicious’ resulted in the formation of many seedless pygmy fruit which persisted until harvest.

Low seed numbers can have an adverse affect on fruit size (Williams 1977), and on fruit quality (Bramlage *et al*. 1990). Thinning agents applied at or after flowering can have a dramatic effect on seed abortion (Williams and Edgerton 1981; Williams 1986). Both NAA and carbaryl can reduce seed numbers in pome fruit or cause abortion of fertilised seeds (Flore 1978; Bound *et al*. 1991a; Jones *et al*. 1998). This problem of reduction in seed numbers increases proportionately the later after full bloom that NAA is applied (Bound *et al*. 1991a). Carbaryl has also been reported to produce small seedless fruit, particularly when applied under cool temperature conditions (Anon 1988) or close to full bloom (Jones *et al*. 1998). Moon and Kim (1986) found that fruit treated with NAA and carbaryl contained smaller seeds than untreated fruit. High rates of endothal have also been shown to reduce seed numbers (Bound and Jones 1997). Ethephon has no effect on seed numbers (Jones *et al*. 1992a; Bound *et al*. 1993a).

If applied under cool temperatures or high humidity carbaryl may cause skin russeting, thus downgrading fruit. NAA may also cause russet under humid conditions. Application of any chemical after a prolonged cool wet period is likely to result in an increase in fruit russet. According to Byers (1997), application of endothal, ammonium thiosulphate (ATS), pelargonic acid, YI-1066 (2-hydroxyethyl-n-octyl-sulfide) and Wilthin™ (monocarbamide dihydrogen sulphate) made in the later stages of bloom (90% open flowers) caused more fruit russeting or marking than applications at earlier stages.

There has been little reported on the effect of thinning chemicals and/or crop load on internal fruit quality parameters such as soluble solids content and firmness. Garriz *et al*. (2000) found fruit flesh firmness was significantly lower in 'Braeburn' trees carrying high crop loads than in trees with moderate or low crop loads. Benzyladenine has also been reported to increase fruit firmness and soluble solids content in 'Delicious' (Bound *et al*. 1997). Bound (1998) reported that addition of adjuvants to BA reduced soluble solids content but had a positive effect on fruit firmness. Bound and Jones (1997) found that endothal increased both soluble solids content and firmness of 'Delicious' and Bound (2001a) reported that the greater the number of applications the greater the increase in fruit firmness and sugar content.

Interactions between chemicals used in a spray program have also been shown to have deleterious effects on crop load and/or fruit quality. Applications of NAA at FB following Cytolin results in severe over thinning, while applying NAA later than 7 dAFB when a Cytolin program has been used produces pygmy fruit (Bound *et al*.

1991a). Use of paclobutrazol on 'Delicious' within 7 days of carbaryl has also been shown to result in excessive fruit thinning (Jones *et al*. 1991b).

3.5: Foliar damage

In general, the development of a complete and healthy early season canopy of spur leaves, and later addition of bourse leaves, is essential for fruit set, fruit growth and quality (Proctor and Palmer 1991).

Desiccating chemicals are becoming increasingly popular as chemical thinning agents, however there have been reports of foliar damage resulting from their use (Irving *et al.* 1989; Southwick *et al*. 1996; Bound and Jones 1997). Although Bound and Jones (1997; 2004) reported the effects of desiccating chemicals used for blossom thinning on some fruit quality attributes, the impact of leaf damage caused by these desiccants on fruit quality is not known. Following removal of whole leaves from spurs and/or bourse shoots, Proctor and Palmer (1991) saw no effect of early season defoliation on mean fruit weight.

Several studies relating to foliar feeding by pests have shown that leaf damage impacts on both size and quality of fruit. Lakso *et al.* (1996) reported reduced fruit growth rates in Starkrimson 'Delicious' trees following European red mite injury of leaves. Other reported effects of mites and other foliar feeders on apples include poor fruit colour, reduced sugar concentrations, and delayed maturity (Zwick *et al.* 1976; Ames *et al.* 1984; Beers *et al.* 1987). However the degree of effect on fruit quality may depend on crop load. Both Marini *et al.* (1994) and Francesconi *et al.* (1996) reported greater decreases in fruit size, colour, and soluble solids concentration in damaged trees with heavy crops than in lightly cropped trees.

Reports on the effect of mite damage on return bloom and cropping are conflicting (Lienk *et al.* 1956; Beers *et al.* 1987; Beers and Hull 1987; 1990; Hull and Beers 1990; Lakso *et al.* 1996). Lakso *et al.* (1996) suggested that, while late season foliar injury would not be expected to be a major factor affecting return bloom as flower buds are initiated early in the season, late season stresses might limit flower bud development, thus potentially limiting final set in the following year. This hypothesis was supported by Francesconi *et al.* (1996), whose results suggested that a low canopy net CO_2 exchange rate late in the previous year has a detrimental effect on flower development for the next year, resulting in poor return crop load.

Proctor and Palmer (1991) found that, while spur leaves were not necessary for flower initiation and expression, removal of bourse leaves had a dramatic effect in reducing return bloom in the three cultivars they studied. Although a number of researchers have shown that spur leaves are necessary for flower initiation and return bloom, they have failed to distinguish between leaf types, thus not allowing for the role of the bourse leaves to be revealed. Both Ramirez (1979) and Hoad and Abbott (1986) [cited in Proctor and Palmer 1991] found little effect of removing primary spur leaves of 'Cox' on subsequent flowering, but removal of bourse leaves almost eliminated flowering.

4. Conclusions

Modern orchard management has the goals of attaining sustainable, high yields coincident with achieving marketable fruit quality within desired fruit size grades (Warrington *et al*. 1996). Link (1993) has suggested that many of the existing problems with fruit quality are caused by growers themselves. Many management options that influence fruit yield and quality – such as tree spacing within and between rows, row direction, rootstock and training system – are determined at the time of orchard establishment and usually remain unchanged for the life of the planting. However, cultural factors such as irrigation, nutrition, pesticide choice and application method, orchard floor management, pruning, crop load management and use of shade and hail netting can be modified at any time after tree establishment to alter productivity and/or fruit quality. Careful planning before orchard establishment will enable minimisation of site factors, however the grower still has considerable room to improve on fruit quality by management of those factors over which there is some control. While soil type influences nutrition and irrigation requirements and site factors can play a role in pest/disease load, recommendations for pruning, shading and crop load management can be more readily applied to a range of situations.

This review has highlighted the importance of reducing crop load early in the season, and of minimising any factors that may limit carbohydrate supply to ensure high fruit quality. However, while there is considerable information available on the impact of many orchard management practices on fruit size and colour, there is a lack of real information available on the impacts of pruning, shading, crop load, and chemical thinning agents on internal fruit quality parameters such as firmness, sugar content and seed number. In addition, the information that is available on the impact of practices such as pruning and chemical thinning on fruit quality is often conflicting, and the impact of crop load on fruit quality is often confounded by the effect of chemicals used to manage crop load. Hence this study examines these aspects in detail in an attempt to clarify these issues and provide practical methods of improving fruit quality.

Chapter 3

General Materials and Methods

1. Location of trials

All the research detailed in this study was undertaken in Tasmania, Australia. In this cool temperate region of the southern hemisphere, budburst occurs in early – mid September, full bloom in early – mid October, harvest from early March through to early May depending on cultivar, and leaf fall is usually around late April – early May. Trials were located in the Huon Valley (43° 07′ south, 147° 01′ east) and at Parramatta Creek (41° 20′ south, 146° 32′ east) (Figure 3.1).

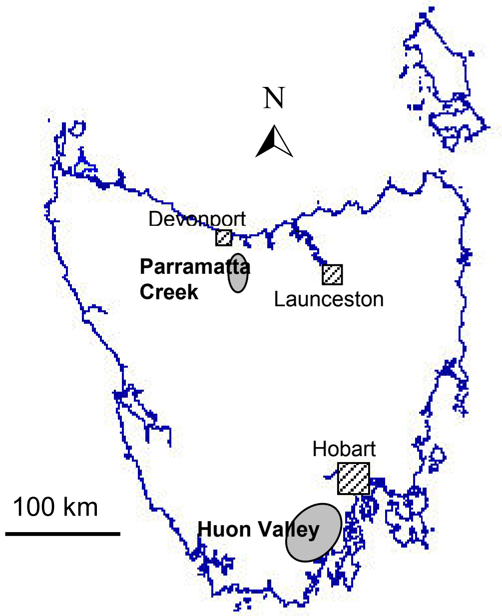


Figure 3.1: *Location of trial sites in Tasmania in relation to major cities.*

2. Tree selection

Trees were selected in early spring of each year for each trial based on uniformity of size and vigour. Trunk girths were measured 10 cm above the graft union and trunk cross-sectional areas (TCSA) calculated using the formula:

$$\textbf{Area} = \text{girth}^2 / 4\pi$$

In trials where trees were larger than 2 m in height, two representative sample limbs were chosen on opposite sides of each tree. The limbs were marked at their bases just below the oldest branch on the limb, girths taken at the marks, and limb cross-sectional areas (LCSA) calculated using the above formula.

Blossom clusters were counted on each tree or marked limb as appropriate, and blossom density (number of blossom clusters/cm^2 TCSA or LCSA) calculated as:

Blossom density = number of blossom clusters / trunk (or limb) area

With the exception of the pruning and shading trials, described in Chapters 4 and 5 respectively, trees in each trial were blocked into blossom density groups and treatments allocated at random to single tree plots within each block.

Details of cultivar, tree age, size and orchard spacing are given in each chapter.

3. Assessments

3.1: Fruit set

Fruit set counts were done in December of each year, after the December fruit drop, and used to calculate the two crop load variables: number of fruit/100 blossom clusters (Jones *et al*. 1983) and number of fruit/cm^2 TCSA (Koen *et al*. 1986).

3.2: Harvest

Fruit was harvested at standard commercial harvest times each season, from March to April depending on cultivar. Trees were strip picked (i.e. all fruit harvested at the same time) according to normal commercial practice unless otherwise stated. Total numbers of fruit per tree were counted and weighed. Mean fruit weight (g) was calculated as:

Mean fruit weight (g) = 1000 * total fruit weight (kg) / total fruit no.

3.3: Fruit size

Fruit was graded on a commercial size grader into increments of 5 mm diameter ranging from 50-95 mm. The percentage of fruit in various size categories (i.e. ≥ 65 mm, ≥ 70 mm, ≥ 75 mm or ≥ 80 mm) was determined depending on cultivar and overall fruit size for each season. Size categories are described in each chapter.

3.4: Fruit quality

Fruit samples were examined for fruit shape (typiness), TSS content, fruit firmness and seed number. Russet levels, starch content and background colour were also assessed in some trials.

Fruit shape was determined by measuring the length and diameter of the fruit using a Vernier calliper and calculating L/D ratios (Bound *et al*. 1991a).

Flesh firmness was measured on pared flesh with a Mecmesin AFG250 force gauge fitted with an Effegi 11 mm penetrometer probe connected to a Mecmesin 2500E motorised stand operating at a speed of 0.65 cm/second.

TSS: juice expressed from the apples during the firmness measurements was collected and TSS concentration (°Brix) was assessed with an Atago PR-1 digital refractometer.

Seeds: apples were sliced horizontally through the equatorial plane and the number of fully developed seeds counted.

Russet: the level of russet on each fruit was determined by examining the skin surface of each fruit and placing into one of the four categories (modified from Bound 2001a) shown in Table 3.1:

Table 3.1: *Russet categories used for classification of fruit (modified from Bound 2001a).*

Category	*fruit surface russeted*
1.	nil
2.	lenticel spot
3.	≤ 10 %
4.	> 10 %

Fruit from categories 1 and 2 is suitable for the export market, while fruit from categories 1, 2 and 3 combined are suitable for the domestic market. Fruit in category 4 is classed as reject, suitable only for processing.

Starch: the cut surface of the calyx bearing half of each fruit was dipped in iodine solution (10 g/L iodine and 40 g/L potassium iodide) for 1 minute. The area of blue/black colouration (indicating the presence of starch) was assessed according to the six point index for the starch staining pattern as described by Little (1999). The higher the starch index the lower the percentage of starch present.

Background skin colour: fruit background colour was measured visually using the scale presented by Frappell and O'Loughlin (1962) (Table 3.2).

***Table 3.2**: Rating scales used for background fruit colour (Frappell and O'Loughlin 1962).*

Rating	Code	Description
1.	G	full green with no trace of yellow
2.	GGY	more green than yellow
3.	GY	green and yellow equal
4.	GYY	more yellow than green
5.	Y	full yellow with no trace of green

3.5: Return bloom

In trials where return bloom was assessed, blossom clusters were counted on each tree, or marked limb as appropriate, during the spring following treatment. Blossom density was calculated as described above.

4. Experimental design and statistical analysis

4.1: Experimental design

All trials were designed as randomised complete blocks, treatment structures are described in each chapter. The number of replicates varied between trials, depending on availability of suitable trees and their uniformity, however a minimum of three replicates and a maximum of eight was used, with most trials having four or five replicates.

4.2: Fruit sampling

Where russet assessments were undertaken, samples of 100 fruit were strip picked from limbs at mid tree height, fruit returned to the packing shed and examined for levels of russet as described above. This fruit was then added to the fruit picked from the rest of each tree before the fruit was graded for size.

For other fruit assessments, samples of 28 fruit per replicate were selected by taking 7 fruit at random from each of the grading bins for the 60, 65, 70 and 75 mm fruit sizes. These fruit were placed into labelled plastic bags and put into cool store until fruit assessments were undertaken. All fruit assessments were commenced within one week of harvest.

4.3: Data analysis and presentation

Data were subjected to analysis of variance using Genstat 5 (Rothamsted Experimental Station, Harpenden, Herfordshire, UK). Tests were performed within Genstat to check all data for normality and homogeneity of variance – all data was found to be normally distributed, hence there was no requirement for any transformation prior to analysis. Linear regressions were undertaken using the Simple Linear Regression option in Genstat.

Data are presented as mean values for each treatment combination. Results described as significant were at a probability level (P) of ≤ 0.05 and Fisher's least significant difference (LSD) ($P = 0.05$), calculated after Steel and Torrie (1980), was used for comparison of treatment means.

Graphs were all plotted using SigmaPlot 2002 for Windows Version 8.02 (SPSS Inc., Gorinchem, The Netherlands).

To enable an understanding of the significance of the results obtained in relation to commercial situations, in trials using the cultivar 'Delicious', crop load and fruit weight/size results were related to commercial target levels as described by Koen *et al*. (1988).

Further details of experimental designs, treatment of data and statistical analysis relevant to individual trials are given in the experimental chapters (Chapters 4-8).

Chapter 4

Influence of degree and time of pruning

1. Introduction

Pruning is used to manipulate tree growth and crop load, both of which impact on fruit quality at harvest. Removal of excess wood in the tree is normally undertaken by pruning during the winter period while trees are dormant. According to Saure (1987), summer pruning, a practice known to European apple growers since the middle of the 17th century but neglected during the 20th century, has regained favour as a means of limiting the size of trees and improving fruit finish and storage quality. Saure used the term ‘summer pruning’ to refer to removal of leafy branches, shoots or parts thereof, irrespective of timing, method or severity. Utermark (1977) has reported that pruning in summer improves light penetration, enhances fruit colour and promotes flower bud formation. However, Marini and Barden (1982) report that light levels were lower in summer pruned trees than in similarly pruned dormant pruned control trees the season following treatment. Removing limbs during the dormant period improves penetration of light into the tree, producing more evenly coloured fruit and encouraging development of next year’s fruit buds (Jones *et al.* 1998). In Australia dormant pruning is often followed by a late summer pruning 4-6 weeks before harvest to remove any of the current season’s growth that is shading fruit.

More Australian growers are tending to leave their dormant pruning until later in the season, with the result that it is often not completed until after flowering. Information on the impact of pruning under Australian conditions is limited, and in light of conflicting reports on the effect of time and type of pruning, this work set out to study standard dormant and summer pruning techniques used in Australia. The aim was to assess the effect of time (winter or spring) and severity of ‘dormant’ pruning, and the interaction with summer pruning (removal of water shoots and current season’s growth) on crop load of 'Fuji' apple, and to determine the impact of these practices on external fruit quality criteria: size, shape and skin finish; and internal parameters: soluble solids content, firmness and seed number.

2. Materials and methods

A trial was established on mature Naga Fu No. 2 ‘Fuji’ trees on MM106 rootstocks at Parramatta Creek. Trees were approximately 2.5 m in height with a planting spacing of 3 m between rows and 2 m within the row.

Trees were blocked into twelve groups, depending on position within the row, and treatments allocated at random to single tree plots within each block. Trunk girths were measured as described in Chapter 3. Trees were pruned in winter while dormant or in spring after flowering to one of three levels: lightly pruned, moderately pruned to current commercial recommendations for Tasmania (Jotic, personal communication), or severely pruned (Figure 4.1). Light pruning involved removal of crossing branches and downward facing spurs on the underside of branches. Moderately pruned trees also had weak branches and water shoots removed in addition to crossing branches and downward facing spurs. In the severely pruned trees all lighter wood was removed, some limbs were removed and main branches cut back to a strong bud.

Pruning was undertaken either in winter, while trees were dormant, or in spring, after fruit set. Thinning cuts (i.e. complete removal of branches) were used in preference to heading cuts. A split plot design was used where half the trial trees were summer pruned 20 wAFB on the 6th March (4 weeks before harvest) to evaluate the effect of summer pruning on fruit quality. Summer pruning involved removal of water shoots and some current season's growth to allow extra light into the trees. Treatment design was a two pruning time (winter/spring) by three severity (light/moderate/severe) by two summer pruning (pruned/not pruned) factorial with six replicates per treatment.

(a) light pruning

(b) moderate pruning

(c) severe pruning

***Figure 4.1**: Pruning levels applied*

All trees were subjected to commercial orchard management practices, including irrigation, chemical thinning and pest and disease management.

Blossom density was not assessed in this trial.

2.1: Assessments

Fruit was harvested at normal commercial harvest time in mid April. All fruit from each tree was counted and weighed, and number of fruit/cm^2 TCSA and mean fruit weight (g) calculated.

Fruit was graded as described in Chapter 3, and number of fruit ≥ 80 mm diameter determined. Fruit samples were assessed for russet, L/D, TSS, firmness and seed numbers as described in Chapter 3.

Total kg fruit/cm^2 TCSA was also calculated for each tree as a measure of yield.

2.2: Data analysis

Data was analysed by analysis of variance as described in Chapter 3. Main effects of time, level and summer pruning were analysed in addition to the various interactions between the three main effects.

3. Results

Crop load, number of fruit/cm^2 TCSA, varied significantly with treatment (Table 4.1). Crop load decreased significantly as pruning severity was increased (Table 4.1(ii)). Neither time of pruning nor summer pruning had any effect on crop load at harvest (Table 4.1(i), 4.1(iii)).

Mean fruit weight and the percentage of large fruit (≥ 80 mm diameter) increased significantly as pruning severity was increased (Table 4.1). While time of pruning had no significant influence on fruit weight or size, the degree of pruning significantly affected both fruit weight and size. Severely pruned trees produced heavier fruit and a higher percentage of fruit in the 80 mm diameter or larger size categories. Summer pruning reduced both fruit weight and fruit size (Table 4.1(iii)).

Yield was significantly reduced by level of pruning, with severe pruning resulting in lower yields than moderate or light pruning (Table 4.1(ii)). There was no effect of time of pruning or summer pruning on yield.

Table 4.1*: The effect of (i) time of pruning, (ii) level of pruning, (iii) summer pruning and (iv) interaction between time of pruning, level of pruning and summer pruning, on crop load, fruit size and yield of 'Fuji' apple.*

	Number of fruit/cm^2 TCSA	Mean fruit weight (g)	% fruit ≥ 80 mm diameter	Yield (kg fruit/ cm^2 TCSA)
(i) time of pruning				
winter	5.6	199.1	39	0.92
spring	4.9	200.9	39	0.84
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*
(ii) level of pruning				
light	6.9	182.6	25	1.08
moderate	5.3	200.2	40	0.88
severe	3.5	217.3	51	0.67
LSD (P=0.05)	*1.00*	*13.61*	*8.8*	*0.12*
(iii) summer pruning				
no summer	5.3	207.3	43	0.92
summer	5.2	192.7	34	0.84
LSD (P=0.05)	*ns*	*11.11*	*7.2*	*ns*
(iv) interaction between time of pruning, level of pruning and summer pruning				
winter pruned - light	7.6	186.1	27	1.26
winter pruned - moderate	6.0	205.6	42	0.99
winter pruned - severe	3.7	237.7	63	0.77
spring pruned - light	5.9	189.2	31	0.98
spring pruned - moderate	4.4	206.8	45	0.82
spring pruned - severe	3.6	218.7	52	0.70
winter pruned – light, summer	7.2	168.3	18	1.00
winter pruned – moderate, summer	5.3	189.8	37	0.83
winter pruned – severe, summer	3.7	207.3	45	0.66
spring pruned – light, summer	6.8	186.8	26	1.09
spring pruned – moderate, summer	5.2	198.8	36	0.90
spring pruned – severe, summer	3.1	205.4	41	0.56
LSD (P=0.05)	*ns*	*ns*	*ns*	*ns*

There were no significant interactions between time of pruning, level of pruning and summer pruning for crop load, fruit weight, fruit size or yield (Table 4.1(iv)). Similarly, the interactions between time of pruning and level of pruning; time of pruning and summer pruning; and level of pruning and summer pruning were not significant (results not shown).

There were significant interactions between pruning treatments on other fruit quality parameters. Fruit L/D ratios increased significantly with increasing severity of pruning in winter pruned trees (Figure 4.2), however, there was no corresponding increase in spring pruned trees. In winter pruned trees, summer pruning significantly reduced fruit L/D ratios compared with non-summer pruned trees.

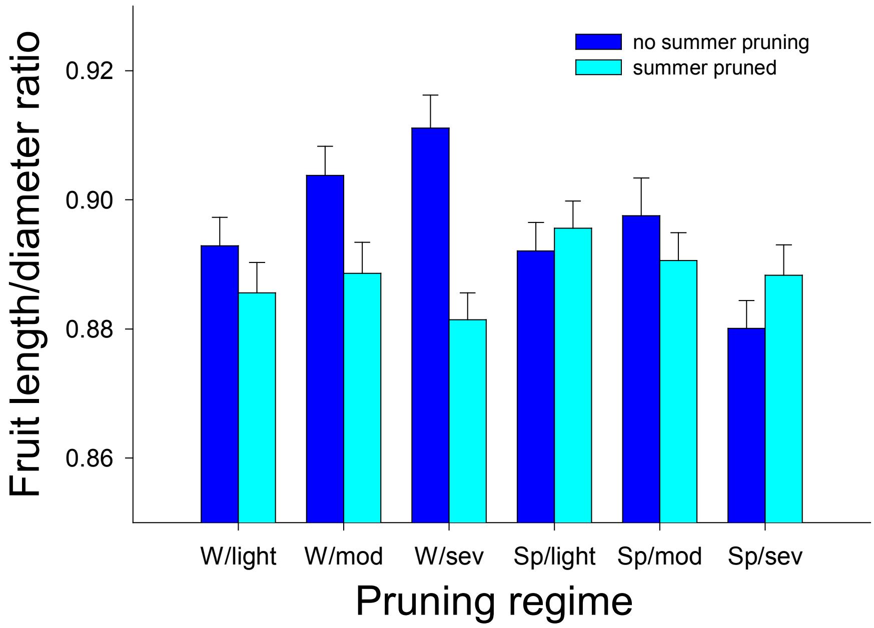


Figure 4.2: *The effect of level and time of pruning on fruit shape (length/diameter ratio) of 'Fuji' apples. LSD (P = 0.05) = 0.012. W, winter; Sp, spring; mod, moderate pruning; sev, severe pruning; light, light pruning.*

Fruit TSS (Figure 4.3) increased significantly with pruning severity in winter, however the converse was true for spring pruned trees. Summer pruning also resulted in significantly reduced TSS.

Fruit firmness (Figure 4.4) was significantly higher in spring pruned trees than in winter pruned for most treatment combinations. Lightly pruned trees also produced significantly firmer fruit than severe pruning except for the spring/severe/summer pruned combination. Summer pruning significantly increased fruit firmness in severely pruned trees and in the light winter pruned trees.

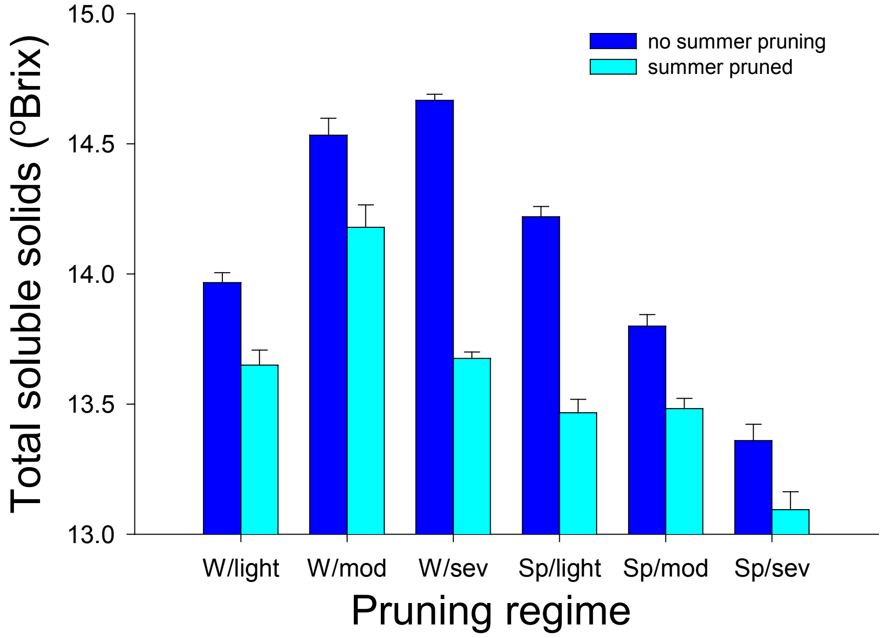


Figure 4.3: *The effect of level and time of pruning on sugar content of 'Fuji' apples. LSD (P = 0.05) = 0.14. W, winter; Sp, spring; mod, moderate pruning; sev, severe pruning; light, light pruning.*

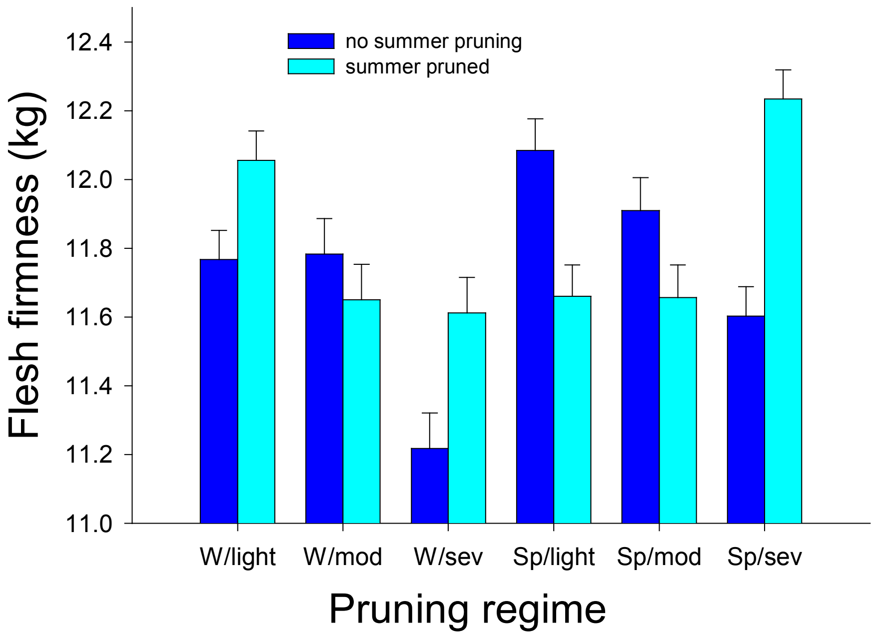


Figure 4.4: *The effect of level and time of pruning on fruit flesh firmness of 'Fuji' apples. LSD (P = 0.05) = 0.26. W, winter; Sp, spring; mod, moderate pruning; sev, severe pruning; light, light pruning.*

There was no significant treatment effect on the number of seeds, with a mean of 6.5 (sd = 0.2) seeds per fruit across all treatments (results not presented).

There were no significant differences between time, level or summer pruning in the percentage of russet free fruit (Table 4.2). Spring pruning resulted in significantly more fruit with > 10% russet compared with winter pruning (Table 4.2(i)). Level of pruning had no significant effect on russet (Table 4.2(ii)).

Summer pruning increased russet levels (Table 4.2 (ii)), resulting in more fruit with > 10% russet than in non-summer pruned trees. There was an interaction between time of pruning and summer pruning, with winter pruning (without summer pruning) showing the highest percentage of russet-free fruit and the least fruit with > 10% russet (Table 4.23(iii)).

Table 4.2*: The effect of (i) time of pruning, (ii) level of pruning (iii), summer pruning, and (iv) interaction between time of pruning and summer pruning on the incidence of fruit russet on 'Fuji' apples.*

	% russet-free fruit (export quality)	% fruit with ≤ 10% russet (domestic quality)	% fruit with > 10% russet (reject)
(i) time of pruning			
winter	18	66	34
spring	14	58	42
LSD (p=0.05)	*ns*	*6*	*6*
(ii) level of pruning			
light	18	65	35
moderate	16	60	40
severe	15	61	39
LSD (p=0.05)	*ns*	*ns*	*ns*
(iii) summer pruning			
no summer	18	65	34
summer	15	59	41
LSD (p=0.05)	*ns*	*6*	*6*
(iv) interaction between time of pruning and summer pruning			
winter no summer	21	72	28
winter summer	15	59	40
spring no summer	14	58	42
spring summer	15	58	42
LSD (p=0.05)	*ns*	*8*	*8*

4. Discussion

The results confirm that pruning does indeed reduce crop load, and furthermore demonstrate that level of pruning is more important than timing in this reduction. Although these results conflict with those of Baart (1989), who reported an increase in number of fruit per 100 flower clusters following winter pruning, they are in general agreement with other reports. Robinson (1994) found that fruit number and yield were reduced linearly with increasing severity of pruning following removal of scaffold limbs during the dormant period, and Katzler and Wurm (1998) reported yield reductions in 'Jonagold' and 'Golden Delicious' following severe pruning. George *et al.* (1996) and Jackson and Palmer (1977a; 1977b) suggested that fruit set and size can both be decreased by competition from vegetative shoots, while Lakso *et al.* (1995) reported that competition from other fruit can decrease fruit set and fruit size. The inverse relationship between pruning level and crop load as reported in this study is also documented by Jones *et al.* (1998), who recommend that, in order to reduce excessive crop loads, pruning should be the first stage in fruit thinning programs.

Fruit weight and size were closely correlated in the work reported here, both being inversely related to crop load. While time of pruning (winter or spring) had no influence on either fruit weight or size, the degree of pruning affected both. Fruit size is the result of the combination of number of cells and cell size (Webster 1997) with cell numbers being determined within the first few weeks of fruit development. Reducing fruit numbers at, or soon after, flowering has the effect of reducing competition for resources between fruit, which may allow remaining individual fruit to develop greater cell numbers. Subsequently, lower fruit numbers will also give individual fruit a greater share of resources allowing cells to increase to the maximum size (Stanley *et al*. 2000).

As the severely pruned trees carried a lighter crop load than the moderately or lightly pruned trees, this is likely to be a major contributing factor to the larger fruit seen in these treatments. Jackson and Palmer (1977a; 1977b) described the adverse effect of shading on fruit size, suggesting that shading affects both cell division and cell size. Although leaf canopy development is not complete until towards the end of, or after, the cell division period, observations suggested that shading within the tree was more pronounced in lightly pruned treatments than in severely pruned treatments. This may be a contributing factor to the smaller fruit produced in lightly pruned trees. According to Jackson and Palmer (1977b) the only way to obtain large fruit under shaded conditions is to reduce their number so that cropping is in balance with the reduced resources. The argument by Warrington *et al.* (1996) that fruit weight is positively related to light transmission within a canopy also supports these findings. Light transmission is higher in severely pruned trees in the early part of the season (Middleton, personal communication), which is the critical period for cell division, and in itself gives the potential for larger fruit.

Vegetative growth in a tree competes with fruit for carbohydrates. Young fruit are known to be weak sinks and both fruit set and size can be decreased by competition from vegetative shoots (George *et al*. 1996; Jackson and Palmer 1977a; 1977b) and other fruit (Lakso *et al*. 1995). Fruit size in this study was not adversely affected by time of pruning, suggesting size is determined by multiple factors determining carbohydrate supply to the fruit during both cell division and expansion. Scholtens (1992) also reported that time of pruning had no effect on fruit weight.

The reduction in both fruit weight and size following summer pruning in this study is consistent with the results of Katzler and Wurm (1998) who reported reduced fruit size of 'Jonagold' following summer pruning. However, Taylor and Ferree (1984) found a reduction in fruit size of ‘Jonathan’ with summer pruning in one season but saw an increase the following season. Comparison of summer pruning responses can be fraught with difficulty as the definition of summer pruning appears to vary greatly between researchers. With some, it is the removal of a proportion of current seasons growth to provide light to the developing fruit, while others use summer pruning partly as a substitute for, or adjunct to, conventional dormant pruning to control tree shape and size. Under Australian conditions, heavily pruned trees tend to exhibit vigorous growth early in the season, much of which is then removed with summer pruning. The reduction in fruit weight and size described here may be due to the removal of a large photosynthetic capacity during the later development period of the fruit, thus reducing fruit growth. According to Li *et al*. (2003a), leaf removal reduces canopy net carbon exchange rate, resulting in less photosynthetic assimilate. The results reported in this present study conflict with the findings of Morgan *et al.* (1984) and Warrington *et al.* (1984) who reported that average fruit size of 'Gala' was slightly reduced when summer pruning was carried out 10 weeks before harvest, but was little affected when the interval before harvest was 4 weeks. This difference may be due to varietal differences, or to environmental conditions such as water availability.

Summer pruning in the present trial generally produced fruit of lower quality in terms of both L/D ratio and TSS. The reduction in leaf:fruit ratio caused by summer pruning appeared to have an adverse effect on fruit quality. While Dietz (1984) concluded that fruit sugar content can be improved by pruning in summer and Li *et al*. (2003b) found that internal fruit quality was unaffected by summer pruning, Morgan *et al.* (1984), Ystaas *et al.* (1992) and Katzler and Wurm (1998) all reported decreased fruit TSS concentration following late summer pruning of trees, agreeing with the results reported here.

This study showed that lightly pruned trees produced the firmest fruit. Warrington *et al.* (1996) reported that the firmest fruits occurred in inner canopy regions, which also had lower light levels. Lower light levels throughout the canopy of lightly pruned trees compared with hard pruned trees may partly explain the firmer fruit produced by the lightly pruned trees in this work. The lack of effect of summer pruning on fruit firmness in this study confirms the report of Taylor and Ferree (1984) with 'Jonathan' apple.

As previously discussed, heavy pruning in winter or early spring encourages vegetative growth and leaf production, with high leaf area possibly enhancing carbohydrate supply. This should have a favourable effect on fruit quality as was seen in the increased TSS and L/D ratios in fruit from the severe winter pruned trees. This however, did not occur in the spring pruned trees, possibly because by the time pruning occurred in spring the competition between vegetative growth and the developing fruit had already compromised fruit quality.

Although level of pruning had no effect on fruit skin finish in the form of russet damage, time of pruning (winter or spring) was important. Russet is scar tissue produced by the fruit when the cuticle or epidermis is ruptured, and forms a protective barrier preventing either pathogen invasion or fruit dehydration. According to Curry (1991), fruit is most susceptible to damage and production of scar tissue in the early weeks after anthesis. The spring pruning treatment in this work was undertaken during this period. Pruning is an invasive procedure involving physical handling of trees and limbs and there is a high potential to damage fruit by mechanical injuries as a result of accidental rubbing, brushing and knocking of the developing fruit by pruners, ladders and removal of branches.

Light is another factor that has been shown to impact on russet (Eccher and Noè 1993; Noè and Eccher 1996). Pruning in spring, after fruit set, opens up the tree canopy and exposes the developing fruit to high light levels at a critical period in development. Conversely, in winter pruned trees, shade is provided to the developing fruit by the vegetative growth that has already been produced by this time. Although summer pruning occurs after the period of greatest potential for russet initiation (Miller 1984), the sudden increased exposure of the fruit to high light levels greatly increases the potential for further expression of russet from already damaged cells. In this study the significant increase in reject fruit due to higher russet scores following summer pruning provides evidence for this hypothesis.

Chapter 5

The effect of overhead netting or fruit bagging

1. Introduction

Adequate light distribution is an important factor influencing apple yield and aspects of fruit quality such as size and colour (Wagenmakers and Callesen 1995). Although light management within an orchard canopy is closely linked to training system, row orientation, planting distances and pruning (as suggested in Chapter 4), there are other factors that can impinge on the light microclimate within a tree.

In many areas of Australia it is becoming commonplace to cover apple orchards with hail netting to protect fruit from damage during hail storms. The reduction in light levels varies depending on the type of netting used. Reduced light levels have been shown to reduce total yields, red colour development, and fruit soluble solids (Jackson 1968; Doud and Ferree 1980; Han and Yoon 2001). Differences in fruit quality parameters between black and white netting and between cultivars have been reported by Stampar *et al*. (2001; 2002), however Widmer (2001) suggested that external and internal fruit quality depends on other factors which are more important than the effect of hail netting.

Enclosing apple fruit in protective bags during development has been practiced widely in Japan for many years (Proctor and Lougheed 1976), and it is also increasingly common for Australian growers sending fruit to specialist markets to bag a proportion of their crop to reduce skin blemishes and enhance colour development. According to Mink (1973), the practice of bagging fruit greatly reduces both fruit flavour and storage ability. Mattheis *et al*. (1996) reported that bagged Fuji fruit grown in Washington state had lower soluble solids content, reduced titratable acidity and decreased firmness at harvest and during storage. There is limited information available on the impact of bagging on fruit quality under Australian conditions.

The aim of this work was to assess the impact of two different grades of netting on crop load and fruit quality and to examine the impact of enclosing fruit in commercial paper apple bags on fruit size, skin finish, shape, TSS content, flesh firmness and seed number.

2. Materials and methods

Three trials were undertaken over two seasons on mature regular bearing Naga Fu No. 2 ‘Fuji’ trees on MM106 rootstocks in the Huon Valley. Trial 1 was established on 11-year-old trees in October of the first season and trials 2 and 3 on trees from the same orchard block in October of the following season. Trees were 2.5-3.0 m in height, trained to a central axis system with a planting spacing of 4 m between rows and 3 m within the row, with rows oriented east-west.

All trees were subjected to commercial orchard management practices, including irrigation, and pest and disease management. Chemical thinning was undertaken in trial 3, but not in trials 1 and 2 where trees were hand thinned 3 wAFB to a crop load of 5-6 fruit/cm^2 TCSA.

Trial 1: Trees were blocked into eight groups, depending on position within the row, and treatments allocated at random to four tree plots within each block, giving eight replicates per treatment. The middle two trees in each plot were tagged for assessments.

Seven treatments consisted of an untreated control, two types of overhead netting and bagging of fruit with paper ‘apple bags’ at different times. The netting used was either white knitted hail netting or green woven shade cloth. To confirm the manufacturer’s specifications in relation to the level of light reduction for each net material, visible light transmission in full sunlight was measured using a solar radiation integrator constructed by the University of Tasmania. Details are provided in Table 5.1. The paper apple bags were Apple Fine Bag No. 8 produced by Hoshino

Yoshiten Co. Ltd, Japan. These bags consist of two layers with the outer bag designed to exclude light (Figure 5.1).

***Table 5.1**: Details of netting.*

			Reduction in light transmission	
Colour	**Mesh size**	**Construction**	**Manufacturer's specification**	**Measured**
White	4 x 4 mm	knitted	17%	18%
green	4 x 2 mm	woven	32%	25%

In the netted treatments, the shade structure was constructed to cover whole trees in each plot. The netting was placed over the appropriate plots 4 wAFB and covered the entire plot approximately 50 cm above tree height, extending to the adjacent row on each side (Figure 5.3). To prevent interplot interference, alternate rows were used. In the bagging treatments fruit were bagged at FB, 2, 4 or 10 wAFB. To ensure pollination occurred in the FB treatments, flowers were bagged after petals started to drop. The bag was placed over the fruit, gathered around the pedicel and secured with the in-built metal tie (Figure 5.2). Bags were designed to allow for fruit expansion and to withstand weathering, but where bags became dislodged during the season, fruit was discarded. The 'outer' bag was removed approximately three weeks before harvest and the 'inner' bag one week after the outer bag to allow fruit to colour.

Trial 2: Trees were blocked into five groups, depending on position within the row, and 14 treatments allocated at random to single tree plots within each block, giving five replicates per treatment.

To explore the effects of time of covering fruit on russet expression, all fruit from each tree were covered with apple bags as used for trial 1. Half of the treatments had pollinated flowers/fruitlets covered at FB, but as for trial 1, treatment was delayed until petal fall to ensure that fruit had been pollinated. Bags were removed at 2, 4, 6, 8, 10, or 12 wAFB, or 3 weeks before harvest. In these treatments the ‘outer’ bag was removed at the designated time followed by the ‘inner’ bag a week later. Fruit which were not covered at FB were covered at 2, 4, 6, 8, 10, or 12 wAFB, and bags remained on the fruit until 3 weeks before harvest (24 wAFB) when the outer bag was removed. The inner bag was removed one week later.

Fruit was always dry at time of bagging and was either bagged or unbagged on the same day. Where bags became dislodged or split during the course of the trial, the fruit was discarded.

Trial 3: Trees were blocked into three groups, depending on position within the row, and five treatments allocated at random to four-tree plots within each block, giving three replicates per treatment.

A shade structure was constructed approximately 50 cm above trees, similar to that used in trial 1. Two types of netting, as used in trial 1 with specified 17% and 32% reduction in light, were placed over the appropriate treatments either 2 or 7 wAFB.

2.1: Assessments

Fruit was harvested in mid April at normal commercial harvest time for all three trials.

Trial 1: fruit from each tree were counted and weighed as they were picked, and mean fruit weight calculated. Fruit were assessed for russet, L/D ratio, TSS, flesh firmness, seed number and starch levels as described in Chapter 3.

Trial 2: russet levels were assessed as described in Chapter 3.

Trial 3: blossom density was assessed in late October. At harvest, fruit from each tree were counted and weighed, and number of fruit/100 blossom clusters and mean fruit weight calculated. Fruit was graded as described in Chapter 3, and number of fruit ≥ 75 mm diameter determined. Fruit samples were also assessed for russet, L/D ratios, TSS and firmness as described in Chapter 3.

Figure 5.1: *apple bags. Left view shows the opaque outer bag cut away and the translucent inner bag*

Figure 5.2: *'Fuji' fruit covered with apple bags*

Figure 5.3: *Erecting shade structure for Trial 1 on 'Fuji' trees. Only the central panel is shown in the photo.*

2.2: Data analysis

All data were analysed by analysis of variance as described in Chapter 3. Regressions between treatments and selected quality parameters were also plotted for the time of bagging treatments in trial 1. In all cases regressions shown are for treatment means and error bars are standard errors of the mean (sem).

3. Results

3.1: Trial 1

Compared with the control, mean fruit weight (Table 5.2) was reduced significantly by both shade treatments and the FB bagging treatment. Both the 2 and 4 wAFB treatments significantly increased fruit weight, while bagging at 10 wAFB had no effect.

Russet-free fruit (export quality) was significantly increased by all treatments compared with the control (Table 5.2), with the exception of the 10 wAFB bagging treatment. Bagging at FB resulted in the greatest number of russet-free fruit. The 32% shade treatment significantly increased the percentage of fruit with ≤ 10% russet (domestic quality), as did bagging at FB and 2 wAFB. The percentage of fruit with ≤ 10% russet was significantly lower in trees bagged 10 wAFB compared with the control. The 32% shade and bagging fruit at FB or 2 wAFB treatments resulted in significantly fewer fruit with > 10% russet (reject). The percentage of reject fruit was significantly higher in the fruit bagged 10 wAFB than in the control. There was a significant negative linear regression between time of application of bags and the percentage of russet-free fruit ($R^2 = 0.95$) (Figure 5.4), and between time of application and percentage of fruit with ≤ 10% russet ($R^2 = 0.98$) (Figure 5.5).

***Table 5.2**: The effect of tree shading or bagging of fruit on mean fruit weight and on the incidence of fruit russet of 'Fuji' apples. FB, full bloom; wAFB, weeks after full bloom.*

	Mean fruit weight (g)	% russet-free fruit (export quality)	% fruit with ≤ 10% russet (domestic quality)	% fruit with > 10% russet (reject)
Control	253	8	82	18
17% shade from 4 wAFB	230	23	87	13
32% shade from 4 wAFB	224	26	91	9
Bag at FB	202	32	94	6
Bag at 2 wAFB	262	23	90	10
Bag at 4 wAFB	270	19	83	17
Bag at 10 wAFB	257	7	72	28
LSD (P=0.05)	*8*	*7*	*6*	*6*

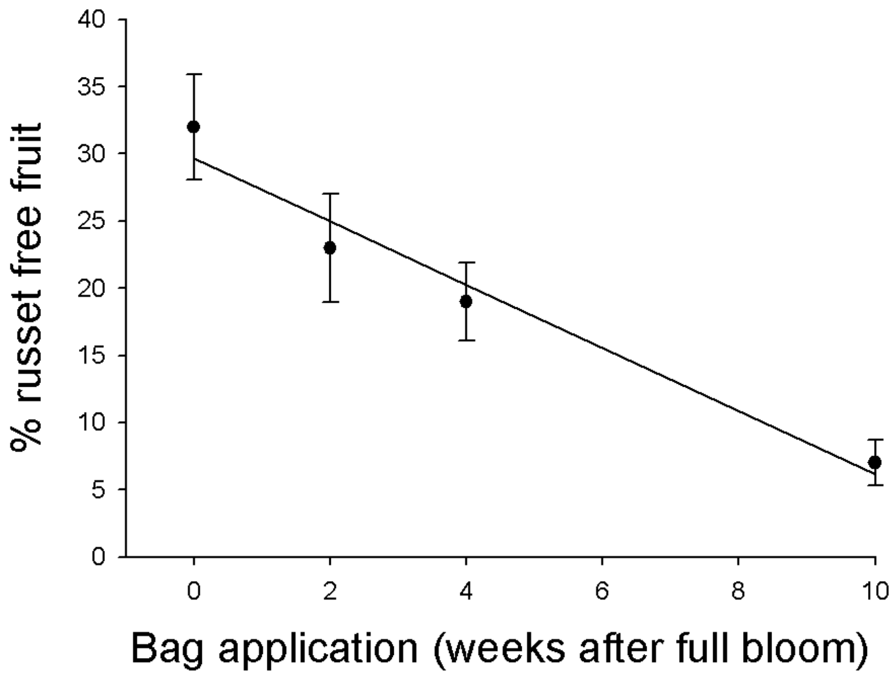


***Figure 5.4**: The effect of time of application of paper apple bags on skin finish (russet-free fruit) of 'Fuji' apple.*
The equation of the line is: $y = 29.7 - 2.36x$, $R^2 = 0.95$, $P = 0.018$

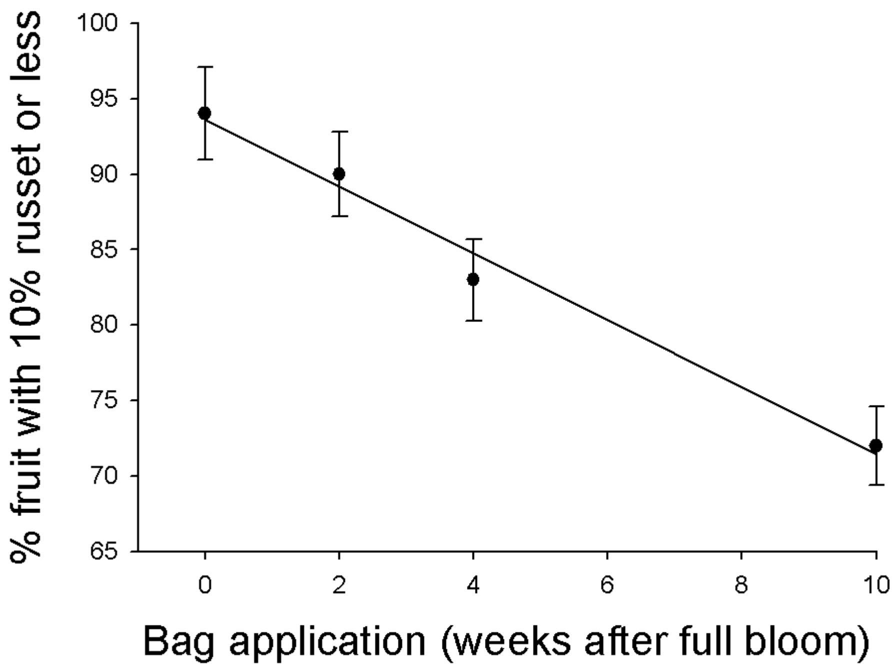


Figure 5.5*: The effect of time of application of paper apple bags on % fruit with ≤ 10% russet of 'Fuji' apple.*
The equation of the line is: y = 93.6 – 2.21x, R^2 = 0.98, P = 0.008

Fruit L/D ratio (Table 5.3) was significantly lower than the control in the 17% shade and 4 and 10 wAFB bagging treatments. Bagging 2 wAFB resulted in more elongated fruit with increased L/D ratios compared with the control. The 32% shade and FB bagging treatments had no effect on fruit shape.

Compared with the control, TSS was significantly reduced by all treatments (Table 5.3). There was no significant difference in TSS levels between the two shade treatments, which were equivalent to bagging fruit 10 wAFB. The later that fruit was bagged the greater the reduction in TSS. There was a significant negative linear regression between time of application of bags and TSS (R^2 = 0.97) (Figure 5.6).

Fruit firmness was significantly increased by the 32% shade treatment, but 17% shade had no effect on firmness. Bagging fruit reduced fruit firmness, with the 4 wAFB treatment having the greatest effect. Seed numbers were significantly reduced by all treatments compared with the control, except for bagging 4 wAFB. The two shade treatments had a greater effect than any of the bagging treatments on seed numbers. Starch levels in the fruit were not significantly affected by the shade treatments when compared with the control. However, the 32% shade treatment produced fruit with a lower starch index than the 17% shade treatment. Bagging at10 wAFB had the lowest starch index.

Table 5.3: *The effect of tree shading or bagging of fruit on fruit shape (length/diameter ratio), total soluble solids content, firmness, seed number and starch index of 'Fuji' apples. FB, full bloom; wAFB, weeks after full bloom.*

	Fruit length/diameter ratio	Total soluble solids (°Brix)	Fruit flesh firmness (kg)	average seed number	Starch index
Control	0.911	14.43	11.37	7.2	4.27
17% shade from 4 wAFB	0.891	13.29	11.54	5.9	4.43
32% shade from 4 wAFB	0.909	13.36	11.69	6.0	4.16
Bag at FB	0.910	14.26	10.88	6.7	4.14
Bag at 2 wAFB	0.920	14.17	10.63	6.8	3.83
Bag at 4 wAFB	0.888	13.84	10.46	7.0	4.06
Bag at 10 wAFB	0.883	13.29	10.89	6.6	3.26
LSD (P=0.05)	*0.008*	*0.09*	*0.19*	*0.3*	*0.23*

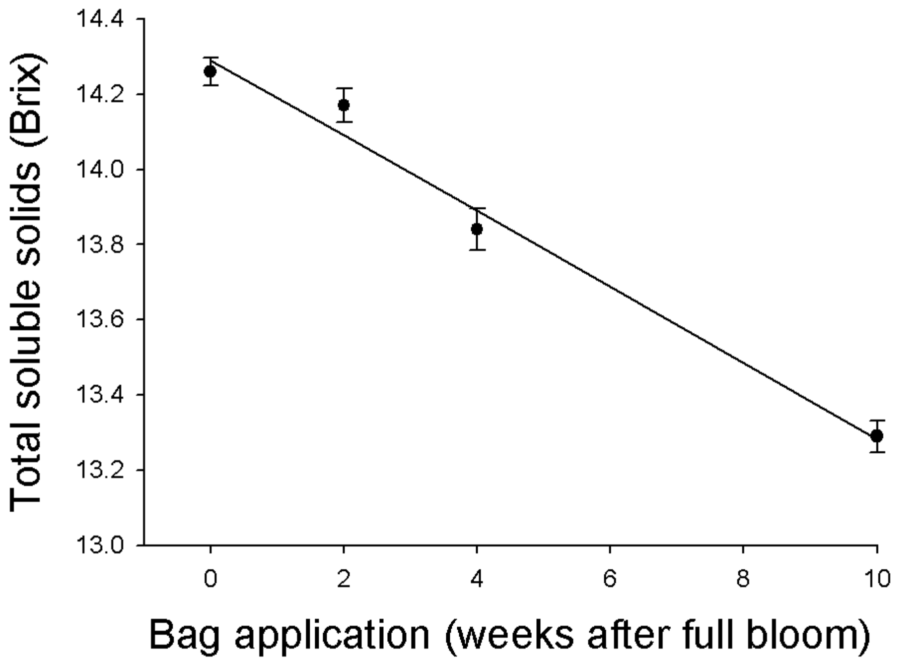


Figure 5.6: *The effect of time of application of paper apple bags on fruit sugar content of 'Fuji' apple.*
The equation of the line is: $y = 14.29 - 0.101x$, $R^2 = 0.97$, $P = 0.008$

3.2: Trial 2

In general, fruit displayed less russet the longer after FB that it remained covered. Treatments bagged at FB or 2 wAFB and uncovered at harvest, or bagged at FB and uncovered from 4-12 wAFB, produced significantly more russet-free fruit than the control (Table 5.4). The later that fruit were uncovered from 4 through to 12 wAFB, the higher the percentage of russet-free fruit. Treatments bagged at FB and uncovered 10 or12 wAFB or at harvest produced the highest percentage of russet-free fruit compared with all other treatments.

The percentage of fruit with > 10% russet (reject fruit) was greatest in the control and treatments bagged 4 wAFB or later and not uncovered until harvest. Fruit bagged at FB and uncovered at 8 wAFB or later produced the least reject fruit. Both sets of data, i.e. fruit covered at different times and uncovered at harvest and fruit covered at FB and uncovered at different times, show that cover from FB to 4-6 weeks later was critical in the reduction of russet in these fruit.

Table 5.4*: The effect of covering fruit with commercial apple bags on the incidence of fruit russet on 'Fuji' apples. FB, full bloom; wAFB, weeks after full bloom.*

	% russet free fruit (export quality)	%fruit with ≤ 10% russet (domestic quality)	% fruit with > 10% russet (reject)
Control	3	28	72
Bag at FB - uncover at harvest	34	90	10
Bag 2 wAFB - uncover at harvest	26	78	22
Bag 4 wAFB - uncover at harvest	5	39	61
Bag 6 wAFB - uncover at harvest	3	35	65
Bag 8 wAFB - uncover at harvest	1	18	82
Bag 10 wAFB - uncover at harvest	1	21	79
Bag 12 wAFB - uncover at harvest	2	23	77
Bag at FB - uncover 2 wAFB	10	61	39
Bag at FB - uncover 4 wAFB	17	74	26
Bag at FB - uncover 6 wAFB	21	80	20
Bag at FB - uncover 8 wAFB	28	91	9
Bag at FB - uncover 10 wAFB	42	94	6
Bag at FB - uncover 12 wAFB	35	84	16
LSD (P=0.05)	*12*	*16*	*16*

3.3: Trial 3

Crop load, expressed as number of fruit/100 blossom clusters, was significantly reduced compared with the control when trees received 32% shade from 2 wAFB, or 17% or 32% shade from 7 wAFB (Table 5.5). At 2 wAFB 32% shade reduced crop load more than 17% shade. The 32% shade from 2 wAFB was the only treatment to significantly reduce fruit weight and fruit size.

Compared with the control, fruit L/D ratio was significantly lower in the treatments shaded from 2 wAFB (Table 5.6). Shading from 7 wAFB had no effect on L/D ratio.

There was no discernible pattern to the effect of time or level of shading on TSS. Both 17% shade from 2 wAFB and 32% shade from 7 wAFB significantly reduced TSS compared with the control, while 32% shade from 2 wAFB and 17% shade from 7 wAFB increased TSS.

Fruit firmness was significantly reduced by both 32% shade treatments, but 17% shade had no effect compared with the control.

All shade treatments significantly increased the level of russet compared with the control (Table 5.7). There was no significant difference between any of the shade treatments.

***Table 5.5**: The effect of shade on crop load, mean fruit weight and size of 'Fuji' apples. wAFB, weeks after full bloom.*

	No. fruit per 100 blossom clusters	Mean fruit weight (g)	% fruit ≥ 75 mm diameter
Control	148	223	84
17% shade 2 wAFB	121	217	83
32% shade 2 wAFB	90	196	71
17% shade 7 wAFB	85	214	78
32% shade 7 wAFB	111	217	85
LSD (P=0.05)	*29*	*17*	*8*

***Table 5.6**: The effect of shade on fruit shape (length/diameter ratio), sugar content and firmness of 'Fuji' apples. wAFB, weeks after full bloom.*

	Fruit Length/diameter ratio	Total soluble solids (°Brix)	Fruit flesh firmness (kg)
Control	0.874	15.78	8.23
17% shade 2 wAFB	0.856	15.63	8.34
32% shade 2 wAFB	0.861	15.95	8.01
17% shade 7 wAFB	0.873	16.06	8.29
32% shade 7 wAFB	0.869	15.17	8.08
LSD (P=0.05)	*0.009*	*0.08*	*0.14*

***Table 5.7**: The effect of shade on the incidence of fruit russet on 'Fuji' apples. wAFB, weeks after full bloom.*

	% russet free fruit (export quality)	% fruit with ≤ 10% russet (domestic quality)	% fruit with > 10% russet (reject)
Control	33	86	14
17% shade 2 wAFB	24	75	26
32% shade 2 wAFB	19	74	26
17% shade 7 wAFB	20	76	25
32% shade 7 wAFB	19	75	25
LSD (P=0.05)	*6*	*7*	*7*

4. Discussion

The results of this work demonstrate that reducing incident light levels can affect crop load and fruit quality, and that both are influenced by the degree of shading and the time that it occurs. Covering fruit with protective paper bags also impacts on fruit skin finish and internal fruit quality, with time of application particularly important in relation to skin finish.

Crop load was not affected by a small reduction in incident radiation early in the season in this study, however higher levels of reduction in incident radiation within 2 weeks after flowering did reduce crop load. The reduced crop load following shading later in the season (7 weeks after flowering) is in general agreement with the findings of McArtney *et al*. (2004), who reported that the effect of shading on fruit abscission of ‘Royal Gala’ was less pronounced when trees were shaded soon after bloom compared with later shade treatments. Several studies have suggested that fruit abscission is extremely sensitive to light limitation for a brief period after full bloom (Schneider 1978; Byers *et al*. 1985; 1990; 1991). According to Polomski *et al*. (1988) brief periods of shading can create a temporary carbohydrate deficit in the fruit that may result in apple fruit abscission. Covering trees with 80% shade cloth for a period as brief as 3 days can stimulate a wave of fruit abscission peaking 10-15 days after removal of the cloth (McArtney *et al*. 2004). Although Doud and Ferree (1980) reported that light reduction from tight cluster stage reduced fruit set by 62%, and Jackson and Palmer (1977b) found that shading trees to receive 37, 25 or 11% of full daylight during the post-bloom season reduced fruitlet retention, these results suggest that small reductions in light levels (17%) around 2 wAFB do not influence crop load. Combined with the results of these authors, the results reported here indicate that both the level and time of shading in relation to the stage of fruit development and tree growth influence the effect on fruit set. Low levels of shading are unlikely to have a major impact on carbohydrate levels within the tree, but the reduced photosynthetic activity that occurs under heavier shading would result in less carbohydrate production and thus influence fruit retention.

This study found that shading earlier in the season does depress fruit weight and size, however shading from 7 wAFB had no effect. The reduction in fruit weight at the earlier shading time agrees with the results of Doud and Ferree (1980) who found that reducing light by 63% from tight cluster stage through to harvest reduced fruit weight in ‘Delicious’. Seeley *et al*. (1980) correlated weight of ‘Delicious’ fruit at harvest with radiant flux density following shading from 45 days post-bloom (approx. 6 wAFB). Shading trees from 55 days (approx. 8 weeks) post-bloom, Robinson *et al*. (1983) reported that as the solar exposure level was reduced, fruit weight of ‘Delicious’ decreased. It was postulated by Jackson (1968) that the reduced fruit size of ‘Cox’s Orange Pippin’ caused by lower light intensities is most probably a result of lower rates of photosynthesis. Reduced fruit size caused by shading has since been shown to be a result of reductions of cell size and number of cells per fruit (Jackson *et al*. 1977). This explains the lack of effect on fruit size with later shading, as cell numbers, and hence potential fruit size, are determined by around 6 weeks after bloom (Webster 1997). Jackson and Palmer (1977b) concluded that the only way to obtain large fruit under shaded conditions is to reduce their number so that cropping is in balance with the reduced resources.

The effect of overhead shading of whole trees on fruit skin finish in this study was conflicting. In one year both 17% and 32% light reduction produced cleaner fruit than the control, however the following year both levels of shade resulted in a higher incidence of russet than the control. There are also conflicting reports by other authors in relation to the effect of shading on fruit skin finish. Damas (1989) found no significant difference in russet incidence between shaded and unshaded trees, while Jackson *et al*. (1977) and Noè and Eccher (1996) demonstrated that shading will reduce the degree of russet on apples. In this present study, the variation in results may be due to climatic differences between seasons. The spring of the second season was very wet (Appendix 2) and increased humidity levels under the netting may have contributed to increased russet levels (Faust and Shear 1972; Creasy 1980; Wilton 1995) in the shaded trees.

Covering fruit early in the growing season with protective apple bags improved fruit skin finish through a reduction in russet. This agrees with the findings of Hong *et al.* (1989) that russeting was decreased by bagging, with lower russet incidence at earlier bagging dates. Most researchers agree that russet is most likely to develop during the period from FB until approximately 4 wAFB (Creasy and Swartz 1981; Skene 1982; Alder 1994). Wertheim (1982) found that the period of rapid growth up to 6 wAFB can put the fruit surface under tension and could predispose the fruit to russet development. As the rate of fruit development during cell division is temperature driven (Warrington *et al*. 1999), the length of the russet sensitive period is likely to be longer in seasons with cool spring weather than those seasons with warm weather (Wilton 1995). The increasing degree of russet with later timing of fruit protection seen in the first year trial suggests that russet damage is not merely the result of one event but may be initiated by several or a series of events. Wilton (1995) has also suggested that russet can result from a combination of several causes. The results of the second year bagging trial showed that fruit protected from FB until 2 or 4 wAFB displayed similar russet levels to fruit protected from 2 wAFB through to harvest, although they were exposed to different environmental conditions and different sprays. This suggests that, in this particular season, russet inducing events occurred later in the season. It should be noted however that skin damage can occur early in the season but need not necessarily result in expression of russet. The amount of russeting depends on the degree of injury and the ability of the epidermal layer to recover (Curry 1991).

While early season shading reduced fruit L/D ratios, shading trees later in the season had no effect. Doud and Ferree (1980) also reported that shading from the tight cluster stage reduced fruit length and width in 'Delicious' apple. However, the lack of effect following shading later in the season conflicts with the results of Seeley *et al*. (1980) and Robinson *et al*. (1983) with 'Delicious' apple. Webster and Crowe (1971) found that 'McIntosh' apples located on wood exposed to sunlight were less elongate than those developing on shaded wood. There may be differences between cultivars, but as it is logical to assume that longer fruit have greater cell numbers than more oblate flattened fruit, this effect is likely to be similar to the effect on fruit size as explained above.

A reduction in fruit sugar content by shading in the first year trial is consistent with the findings of Doud and Ferree (1980), Seeley *et al*. (1980) and Robinson *et al*. (1983) for ‘Delicious’, and Chen *et al*. (1998) for ‘Cox’s Orange Pippin’. This contrasts with the results of Widmer (2001) who reported no effect of shading on sugar content in a range of cultivars, and Stampar *et al*. (2001) who reported increased sugar content in shaded ‘Jonagold’ and ‘Elstar’ trees. Although Stampar *et al*. (2001) observed differences in fruit sugar content between black and white netting, these differences may have been due to differences in light reduction (21%

and 6% respectively), and not to the colour of the netting. The inconsistency of results in the second year between level and time of shading in the work reported here cannot be explained, but perhaps suggest that colour of netting is not critical. Widmer (2001) also concluded that net colour had no influence on fruit sugar levels. Stampar *et al.* (2002) concluded that the influence of crop load and seasonal climatic conditions on internal fruit quality parameters such as fruit sugar content was higher than the influence of hail netting.

Although it appears that net colour most likely does not affect fruit sugar content, Shahak *et al*. (2003) reported that fruit size and colour were differentially affected by nets of various chromatic/optical properties, but that sunburn prevention was merely related to the shading factor of the nets. In studies on the effect of bird netting on orchard microclimate, Blackburn (2002) demonstrated that net colour influenced solar radiation input to the ground. It was reported that white netting reduced solar radiation by 8-10% more than black netting, suggesting that profuse light scattering at the white net creates an overhead glare, a large proportion of which is reflected back to the sky. Blackburn also reported that air temperatures under netting were lower in warmer daytime conditions and marginally higher on nights of cold conditions. Hence it would appear that both microclimate and incident radiation are affected by netting, and further studies are required to enable a full understanding of the impact of net colour and density on fruit growth and quality.

Protecting fruit with paper bags reduced soluble solids content, with greater reductions the later that fruit was covered. This agrees with the report of Robinson (1974) that bagged apples are inferior to unbagged apples in total and reducing sugars. Mattheis *et al*. (1996) also found that bagged 'Fuji' fruit had lower soluble solids content. While fruit firmness was also reduced by bagging, fruit bagged at 2 and 4 wAFB was softer than later bagged fruit. At this later time, fruit also showed higher levels of starch and increased firmness. As sugar content, starch levels and firmness are all indicators of fruit maturity, this suggests that maturity may have been delayed.

The results of shading on fruit firmness were conflicting, with 32% light reduction increasing firmness in one year but decreasing firmness the second year. Reports by other authors on the effect of shading on fruit firmness are also conflicting. Sansavini *et al.* (1981) and Robinson *et al.* (1983) found that apple fruit firmness was increased by the reduced light levels produced through shading. This concurs with the finding of Warrington *et al.* (1996) that the firmest fruits occurred in inner canopy regions, which also had lower light levels. However, Widmer (2001) reported no effect on fruit firmness with shading, and Campbell and Marini (1992) concluded that flesh firmness was not consistently affected by any measure of canopy light levels. It is likely that fruit firmness is influenced by many factors that are more important than the effect of shade produced by netting, as concluded by both Widmer (2001) and Stampar *et al*. (2002).

Seed numbers were lower in the shaded and early season covered fruit, suggesting that the lower light levels may reduce pollination or affect seed development. Although the reduction in seed number was statistically significant, in biological terms it was relatively small (with the lowest average seed number being 5.9 compared with 7.2 in the control) and thus the effect on fruit quality is not likely to be large. However, consideration should be given to ensuring that other factors that may further reduce seed numbers are avoided when trees are shaded or fruit bagged, as low seed numbers can have important ramifications in terms of senescent breakdown (Bramlage *et al.* 1990) and the incidence of uneven shaped fruit (Proctor and Schechter 1992). Proctor and Schechter (1992) have also linked low seed numbers to smaller fruit.

Chapter 6

Crop load and fruit quality

1. Introduction

Crop load has a direct bearing on fruit weight and size (Quinlan and Preston 1968; Looney 1986; Johnson 1992; 1994; Jones *et al.* 1992b). Increased photosynthate accumulation in the fruit in trees with high leaf:fruit ratio results in increased fruit weight (Fallahi and Simons 1996). Although it has been shown that blossom thinning is desirable to achieve maximum fruit size (Jones *et al.* 1992b; McArtney *et al.* 1996), the only way this can be achieved economically has been with the use of chemicals.

While the effect of crop load on fruit weight and size, and on return bloom is well reported, there is limited information available about how crop load and time of thinning impact on other fruit quality attributes such as fruit shape, skin finish, sugar content and firmness. Thinning has been reported to increase susceptibility to physiological storage disorders (Johnson 1992), and fruit from naturally light cropped trees show an increase in problems such as bitter pit, lenticel blotching, watercore, soft scald and browning disorder (Hansen 1997). These reports have led to concern that, although thinning may increase fruit weight and size, it may be detrimental to other aspects of fruit quality.

Most studies relating crop load to fruit quality involve the use of thinning chemicals. These chemicals also affect fruit quality (Link 1967; Wertheim 1974; Flore 1978; Williams and Edgerton 1981; Jones *et al*. 1988; Bound *et al*. 1993a; 1993b; Greene 1993b; Byers 1997), thus clouding the understanding of the impact of reducing crop load on fruit quality. As there are many situations where growers are loath to apply chemicals, particularly on younger trees or high value cultivars, further examination of the impact of crop load on fruit quality is warranted. When hand thinning is undertaken by growers, either in preference to, or to complement inadequate chemical thinning, it is often not completed until 2 - 3 months after flowering. To investigate the effects of crop load on fruit quality independent of any possible direct influences of chemical thinners, the trials presented in this chapter studied the effects of time and level of thinning done without chemicals on fruit quality for several apple cultivars.

2. Materials and methods

Six trials were undertaken across a range of cultivars over a four year period. All trials were conducted in the Huon Valley on mature regular bearing trees. Details of cultivars, rootstock, tree age, height and planting spacings are given in Table 6.1.

Table 6.1: *Details of cultivars used in each trial*

Trial	*Cultivar*	*Rootstock*	*Height (m)*	*Age (years)*	*Planting spacing*
1	'Fuji'	MM106	2.5	9	4 m between rows 3 m within row
2	'Fuji'	MM106	2.5	10	4 m between rows 3 m within row
3	'Delicious'	MM106	2.0	8	4 m between rows 2.5 m within row
4	'Delicious'	MM106	2.2	10	4 m between rows 2.5 m within row
5	'Pink Lady'	M26 MM106	2.0 3.0	7	3 m between rows 2 m within row
6	'Gala'	M26	2.0	6	3 m between rows 1.5 m within row

Trees in all trials were trained to a central axis system. Apart from thinning, all trees were subjected to commercial orchard management practices, including fertilisers, irrigation, and pest and disease management.

Trial 1: Naga Fu No. 2 'Fuji' trees on MM106 rootstocks were blocked according to blossom density, and five treatments allocated at random to single tree plots within each block, giving five replicates per treatment.

The date of FB was 17th October and treatments were hand thinned 6 wAFB on 27th November, to crop loads of 2, 4, 6, 8 or 10 fruit/cm^2 TCSA.

Trial 2: To confirm that results from trial 1 were not affected by seasonal conditions, the same design and treatments were repeated the following season in the same orchard block, but on different trees. The date of FB was 14th October and trees were hand thinned 6 wAFB on 25th November.

Trial 3: Oregon Spur 'Delicious' trees were blocked into five groups, based on blossom density, and five treatments allocated at random to single tree plots within each block, giving five replicates per treatment.

Treatments were hand thinned 6 wAFB, on 2nd December, to crop loads of 2, 4, 6, 8 or 10 fruit/cm^2 TCSA. Full bloom occurred on 21st October.

Trial 4: Thirty six Oregon Spur 'Delicious' trees were blocked into three groups, based on blossom density, and 12 treatments allocated at random to single tree plots within each block, giving three replicates per treatment.

Treatments consisted of a factorial combination of two crop loads (3 or 6 fruit/cm^2 TCSA) and six thinning times (1, 2, 4, 8, 12 or 16 wAFB). Full bloom occurred on 18 October, and treatments were hand thinned on 24th October, 31st October, 14th November, 12th December, 9th January, or 5th February.

Trial 5: Forty eight 'Pink Lady' trees on each of two rootstocks (M26 and MM106) were blocked into four groups, based on blossom density, and treatments allocated at random to single tree plots within each block, giving four replicates per treatment.

Treatments consisted of a factorial combination of two rootstocks, three crop loads (4, 6 or 8 fruit/cm^2 TCSA) and four thinning times (2, 6, 10 or 14 wAFB). Full bloom occurred on 6th October, and treatments were hand thinned on 20th October, 17th November, 15th December, or 13th January to the required crop loads.

Trial 6: Forty eight 'Gala' trees on M26 rootstocks were blocked into four groups, based on blossom density, and 12 treatments allocated at random to single tree plots within each block, giving four replicates per treatment.

Treatments consisted of a factorial combination of three crop loads (3, 6 or 9 fruit/cm^2 TCSA) and four thinning times (2, 6, 10 or 14 wAFB). Full bloom occurred on 11th October, and treatments were hand thinned on 25th October, 22nd November, 20th December, or 21st January to the required crop loads.

In all trials, hand thinning involved removal of small and damaged fruit in preference to larger fruit. Where possible, clusters were thinned to single fruit, but if there was insufficient fruit on the tree to allow this, clusters were thinned to two or three fruit, selecting the larger fruit to remain on the tree.

2.1: Assessments

Fruit was harvested at normal commercial harvest time for all cultivars. Fruit from each tree were counted and weighed as they were picked, and mean fruit weight calculated. Fruit was graded as described in Chapter 3 and the percentage of fruit ≥ 75 mm diameter determined for trials 1-5. As 'Gala' is a genetically small apple and average fruit size for this season was small, percentage of fruit ≥ 65 mm diameter was determined for 'Gala' in trial 6.

Fruit were assessed for L/D, TSS and flesh firmness as described in Chapter 3. Samples of fruit from trial 3 were placed into cool storage at 1°C for 3 months and then assessed for TSS and firmness. Russet was assessed in trial 4, and seed numbers counted in trials 1, 3, 4 and 6. Starch levels and fruit background colour were assessed for 'Gala' in trial 6.

Return bloom was determined for all cultivars except for 'Fuji' in trials 1 and 2, as described in Chapter 3.

2.2: Data analysis

Where the treatment design was a factorial (trials 4, 5, 6), data were analysed by analysis of variance as described in Chapter 3. Regressions were plotted where appropriate to illustrate linear responses to crop load or relationships between measured variables in trials 1, 2 and 3. In all cases regressions shown are for treatment means and error bars are standard errors of the mean.

3. Results

Actual crop loads obtained in trials 1-3 were relatively close to target crop loads (Table 6.2). In trial 4, crop loads achieved were higher than the target in all but one treatment. Mean crop loads achieved in trial 5 were within 0.8 fruit/cm^2 TCSA of the target. In trial 6, all crop loads were within 0.8 fruit/cm^2 TCSA of the target except at 6 wAFB where crop loads were higher.

***Table 6.2**: Mean crop loads (± standard deviation) obtained for each treatment in Trials 1-6. All values are number of fruit/cm^2 trunk cross-sectional area. wAFB, weeks after full bloom.*

(i) Trials 1-3: 'Fuji' and 'Delicious'

Target crop load	Trial 1 'Fuji'	Trial 2 'Fuji'	Trial 3 'Delicious'
2	2.1 (± 0.5)	2.3 (± 0.4)	2.0 (± 0.1)
4	4.2 (± 0.2)	4.2 (± 0.2)	4.4 (± 0.2)
6	5.8 (± 0.5)	6.9 (± 0.4)	6.1 (± 0.4)
8	7.9 (± 0.8)	8.1 (± 0.3)	7.8 (± 0.7)
10	11.0 (± 1.6)	10.0 (± 0.2)	9.9 (± 0.4)

(ii) Trial 4: 'Delicious'

Time	Target	Actual	Target	Actual
1 wAFB	3	3.7 (± 0.5)	6	7.8 (± 0.7)
2 wAFB	3	4.3 (± 0.2)	6	7.6 (± 1.2)
4 wAFB	3	4.6 (± 0.8)	6	7.6 (± 1.3)
8 wAFB	3	4.7 (± 0.3)	6	7.9 (± 0.1)
12 wAFB	3	3.7 (± 0.5)	6	6.6 (± 0.5)
16 wAFB	3	3.6 (± 0.7)	6	5.7 (± 1.1)

(iii) Trial 5: 'Pink Lady'

Time	crop load	M26	MM106
2 wAFB	4	4.0 (± 0.3)	4.1 (± 0.5)
	6	6.2 (± 0.7)	6.1 (± 0.6)
	8	8.4 (± 0.4)	8.6 (± 1.4)
6 wAFB	4	3.5 (± 0.4)	3.9 (± 0.2)
	6	6.2 (± 0.3)	5.7 (± 0.3)
	8	8.1 (± 1.2)	7.6 (± 1.0)
10 wAFB	4	4.1 (± 0.2)	3.9 (± 0.4)
	6	6.3 (± 0.6)	6.2 (± 0.5)
	8	8.0 (± 0.3)	8.2 (± 0.3)
14 wAFB	4	4.0 (± 0.2)	3.9 (± 0.1)
	6	5.9 (± 1.0)	5.9 (± 0.5)
	8	8.2 (± 0.7)	8.3 (± 1.7)

(v) Trial 6: 'Gala'

Time	Target	Actual	Target	Actual	Target	Actual
2 wAFB	3	3.4 (± 0.6)	6	6.2 (± 1.4)	9	9.4 (± 0.9)
6 wAFB	3	4.1 (± 0.5)	6	7.4 (± 0.4)	9	10.3 (± 0.7)
10 wAFB	3	3.2 (± 0.3)	6	6.3 (± 0.2)	9	9.6 (± 0.3)
14 wAFB	3	3.8 (± 0.2)	6	6.6 (± 0.2)	9	9.2 (± 0.8)

3.1: Trial 1 - 'Fuji'

There was a significant linear regression ($R^2 = 0.76$) between crop load and mean fruit weight (Figure 6.1), with a reduction of 15.25 g for every unit increase in crop load. The regressions between fruit size, represented as percentage of fruit ≥ 75 mm diameter, and crop load (Figure 6.2), and between fruit TSS and crop load (Figure 6.3) were also significant ($R^2 = 0.75$ and 0.86 respectively).

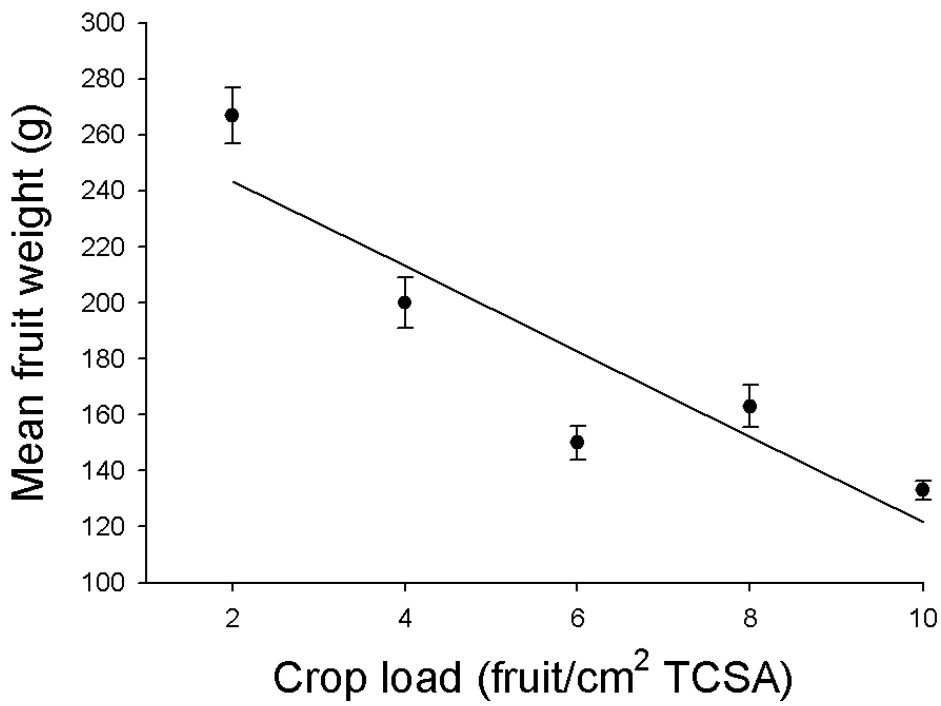


***Figure 6.1**: The effect of crop load on mean fruit weight of 'Fuji' apple. The equation of the line is:* $y = 274.1 - 15.25x$, $R^2 = 0.76$, P = 0.034

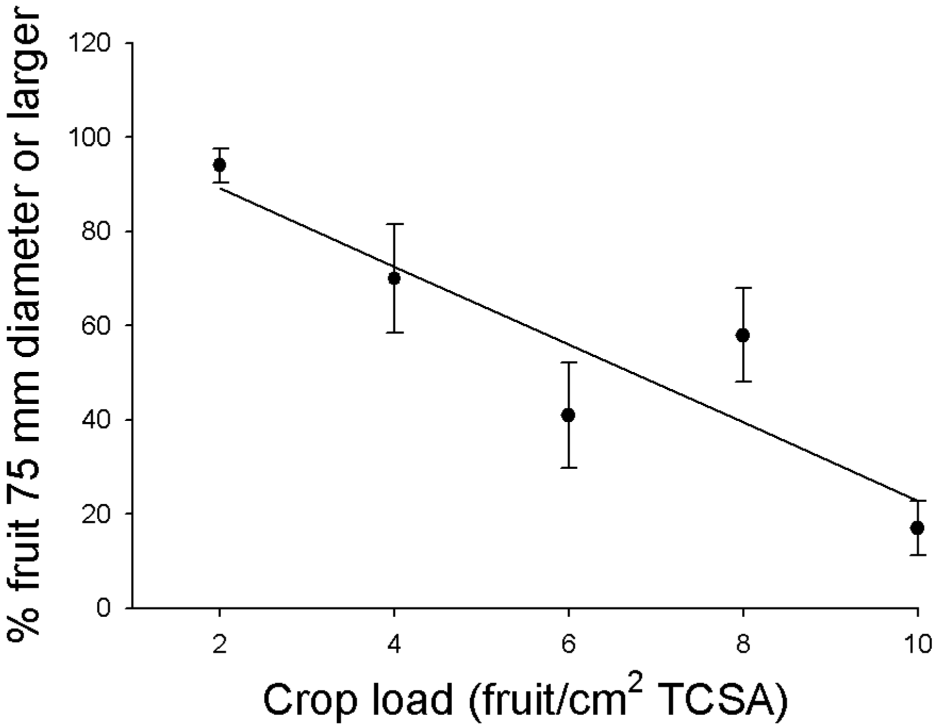


Figure 6.2*: The effect of crop load on fruit size of 'Fuji' apple.*
The equation of the line is: y = 105.8 - 8.30x, R^2 = 0.75, P = 0.037

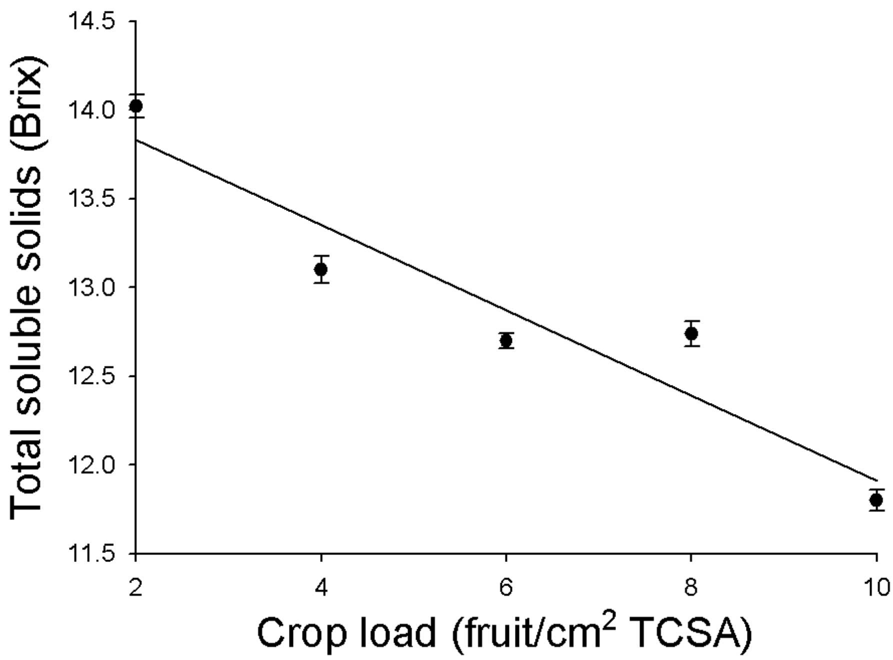


Figure 6.3*: The effect of crop load on fruit sugar content of 'Fuji' apple.*
The equation of the line is: y = 14.312 - 0.24x, R^2 = 0.86, P = 0.014

A crop load of 2 fruit/cm^2 TCSA produced fruit with significantly higher L/D ratio than all other treatments, but there was no significant difference in L/D ratio between crop loads of 4 to 10 fruit/cm^2 TCSA (Table 6.3).

Trees with crop loads of 2, 4 and 10 fruit/cm^2 TCSA produced significantly firmer fruit than 6 fruit/cm^2. Seed number was significantly higher at 10 fruit/cm^2 TCSA than at 6 or 2 fruit/cm^2 TCSA.

Table 6.3*: The effect of crop load on fruit shape (length/diameter ratio), flesh firmness and seed number of 'Fuji' apples hand-thinned 6 weeks after full bloom. TCSA, trunk cross-sectional area.*

	Fruit length/diameter ratio	Fruit flesh firmness (kg)	Number of seeds per fruit
2 fruit/cm^2 TCSA	0.920	12.11	6.1
4 fruit/cm^2 TCSA	0.896	12.28	7.0
6 fruit/cm^2 TCSA	0.893	11.74	6.9
8 fruit/cm^2 TCSA	0.891	11.95	7.0
10 fruit/cm^2 TCSA	0.886	12.36	7.6
LSD (P=0.05)	*0.012*	*0.35*	*0.6*

There was a significant regression between mean fruit weight and fruit sugar content (Figure 6.4) and between mean fruit weight and fruit shape, represented by fruit L/D ratio (Figure 6.5) (R^2 = 0.87 and 0.90 respectively).

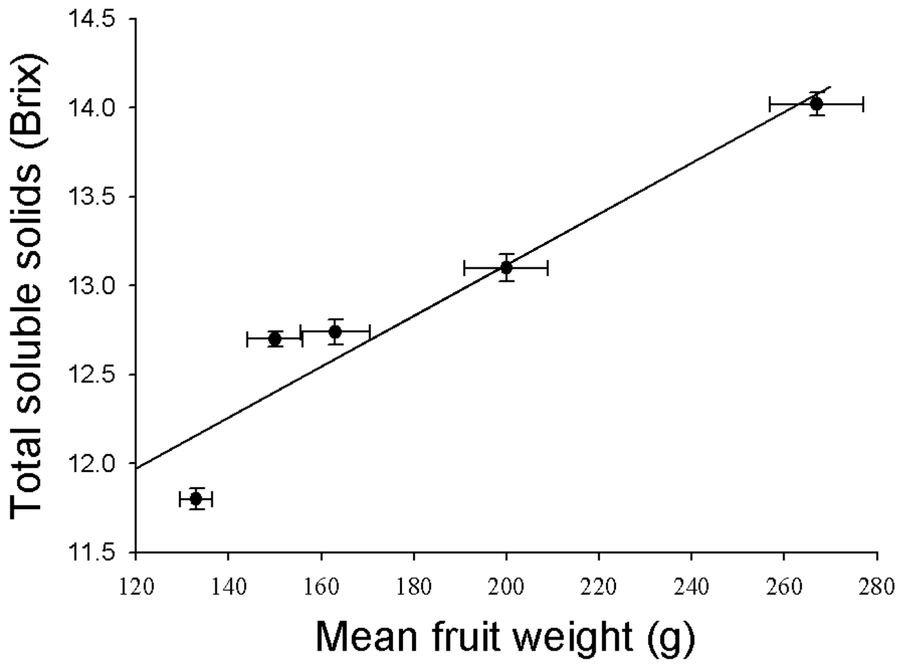


Figure 6.4: *The relationship between fruit weight and sugar content of 'Fuji' apple.*
The equation of the line is: y = 10.258 + 0.01431x, R^2 = 0.87, P = 0.013

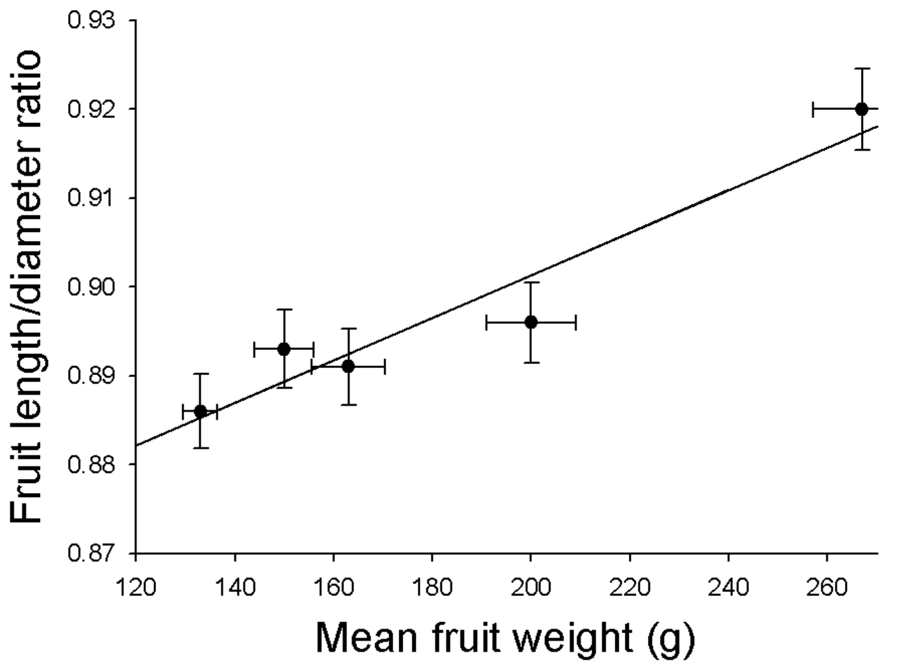


Figure 6.5: *The relationship between fruit weight and shape (length/diameter ratio) of 'Fuji' apple.*
The equation of the line is: y = 0.8534 + 0.0002398x, R^2 = 0.90, P = 0.009

3.2: Trial 2 - 'Fuji'

As for trial 1, there was a significant linear regression between mean fruit weight and crop load (Figure 6.6), with a reduction of 11 g for every unit increase in crop load (R^2 = 0.90). The percentage of fruit ≥ 75 mm diameter was also inversely correlated with crop load (Figure 6.7), as for trial 1, and there was a significant linear regression between fruit TSS and crop load (Figure 6.8) (R^2 = 0.83 and 0.85 respectively).

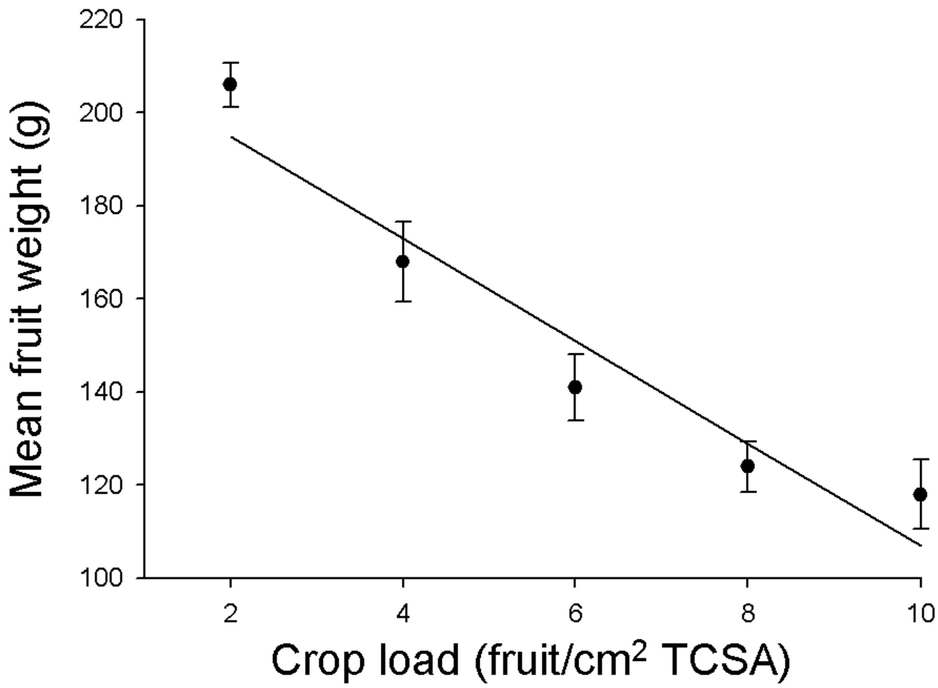


***Figure 6.6**: The effect of crop load on mean fruit weight of 'Fuji' apple. The equation of the line is:* y = 217 - 11x, R^2 = 0.90, P = 0.009

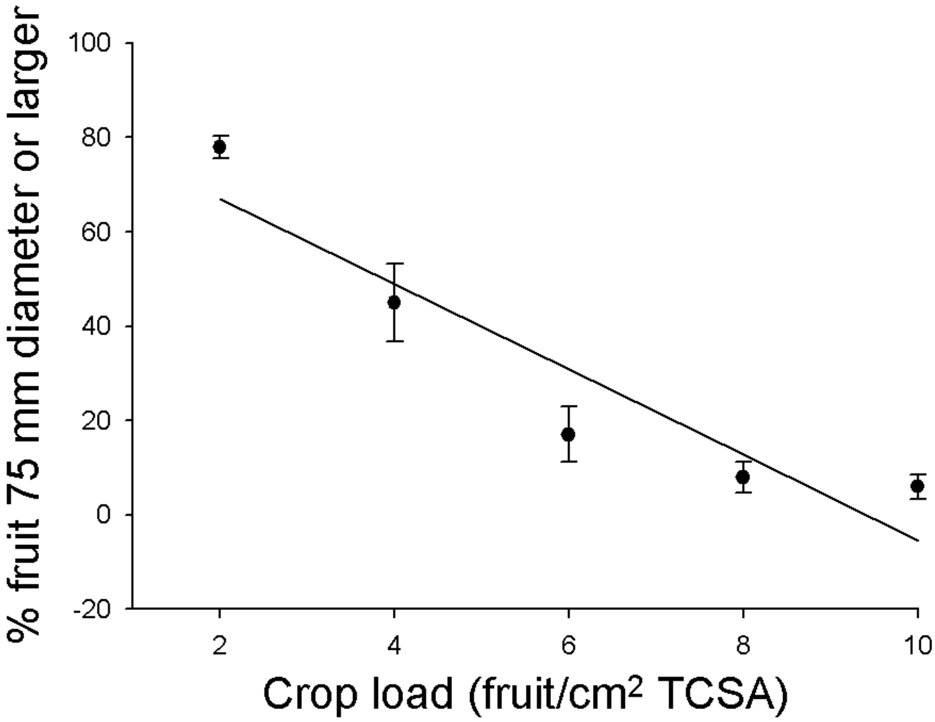


Figure 6.7*: The effect of crop load on fruit size of 'Fuji' apple.*
The equation of the line is: y = 85.1 - 9.05x, R^2 = 0.83, P = 0.020

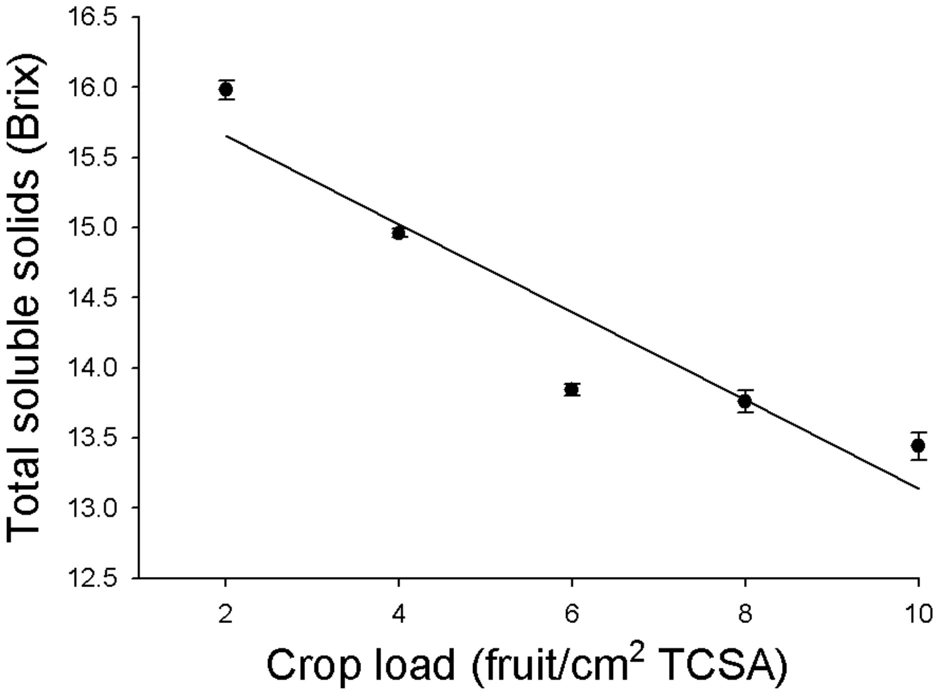


Figure 6.8*: The effect of crop load on fruit sugar content of 'Fuji' apple.*
The equation of the line is: y = 16.28 - 0.314x, R^2 = 0.85, P = 0.017

There was a significant linear regression between fruit weight and fruit sugar content (Figure 6.9), with an increase of 0.014 °Brix for every gram increase in fruit weight ($R^2 = 0.87$).

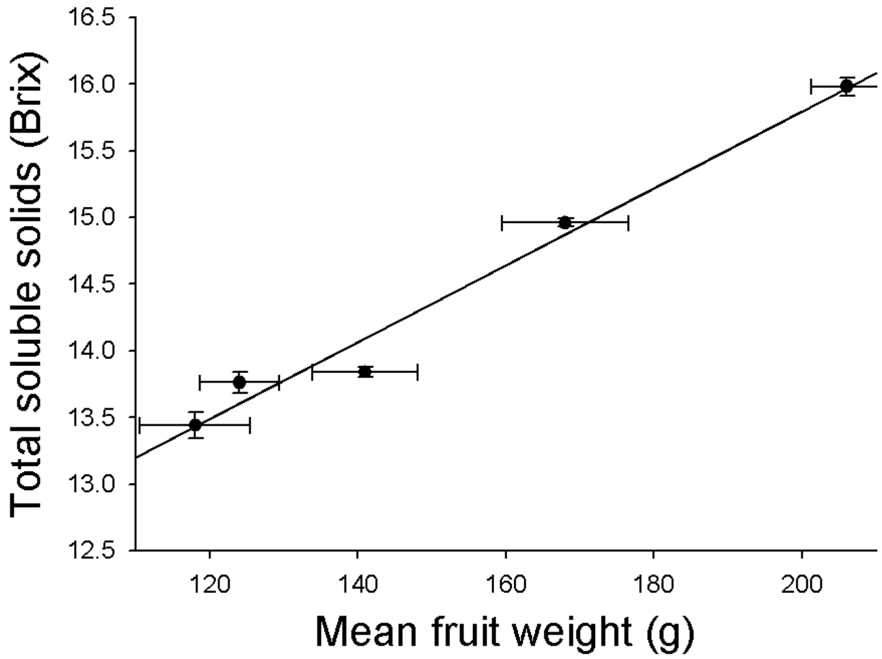


Figure 6.9: *The relationship between fruit weight and sugar content of 'Fuji' apple. The equation of the line is:* $y = 10.258 + 0.01431x$, $R^2 = 0.87$, $P = 0.013$

As shown in Table 6.4, fruit L/D ratio was highest at crop loads of 2 and 4 fruit/cm^2 TCSA. There was no significant difference in L/D ratio between crop loads of 2 and 8 fruit/cm^2 TCSA, or between crop loads of 6, 8 and 10 fruit/cm^2 TCSA.

Trees with a crop load of 2 fruit/cm^2 TCSA produced significantly firmer fruit than all other treatments. Fruit from trees with a crop load of 10 fruit/cm^2 TCSA had significantly softer fruit than 6 and 8 fruit/cm^2 TCSA. There was no significant difference in firmness between treatments with crop loads of 4, 6 or 8 fruit/cm^2 TCSA.

***Table 6.4**: The effect of crop load on fruit shape (length/diameter ratio) and flesh firmness of 'Fuji' apples hand-thinned 6 weeks after full bloom. TCSA, trunk cross-sectional area.*

Crop load	Fruit length/diameter ratio	Fruit flesh firmness (kg)
2 fruit/cm^2 TCSA	0.854	8.25
4 fruit/cm^2 TCSA	0.859	7.60
6 fruit/cm^2 TCSA	0.839	7.78
8 fruit/cm^2 TCSA	0.843	7.82
10 fruit/cm^2 TCSA	0.841	7.51
LSD (P=0.05)	*0.012*	*0.22*

3.3: Trial 3 - 'Delicious'

As for 'Fuji', there was a significant negative linear regression between crop load and fruit weight (R^2 = 0.85), with a reduction of 10.45 g for every unit increase in crop load (Figure 6.10), and between crop load and fruit size (Figure 6.11) (R^2 = 0.97).

There was a significant regression between fruit TSS and crop load (Figure 6.12), with a reduction of 0.109 °Brix for every unit increase in crop load (R^2 = 0.69). A similar relationship was present following cold storage of fruit, but the reduction in °Brix for every unit of crop load increased to 0.162 (Figure 6.13).

Fruit flesh firmness decreased with increasing crop load from 2 to 6 fruit/cm^2 TCSA (Table 6.5). There was no significant difference in firmness between the 6, 8 or 10 fruit/cm^2 TCSA treatments. Increasing crop load had no significant effect on fruit L/D ratio or on seed number.

Following cold storage of fruit, there was a significant inverse linear regression between fruit firmness and crop load (Figure 6.14) (R^2 = 0.73).

There was a significant positive linear regression between fruit weight and fruit sugar content (Figure 6.15), between fruit weight and flesh firmness (Figure 6.16), and between fruit sugar content and firmness (Figure 6.17) (R^2 = 0.97, 0.90 and 0.98 respectively).

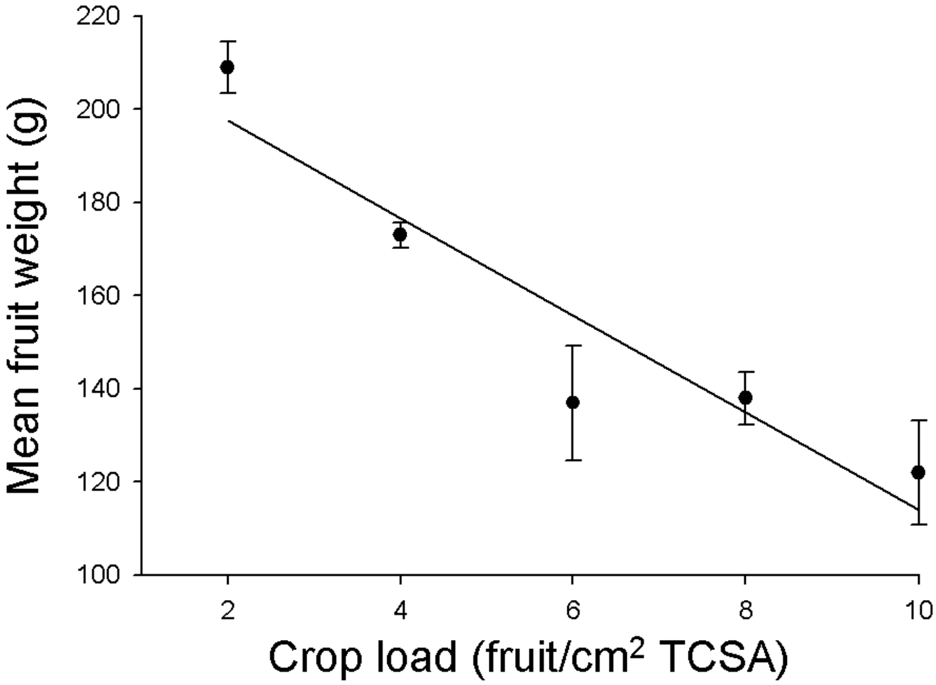


Figure 6.10*: The effect of crop load on mean fruit weight of 'Delicious' apple. The equation of the line is:* y = 218.5 - 10.45x, R^2 = 0.85, P = 0.017

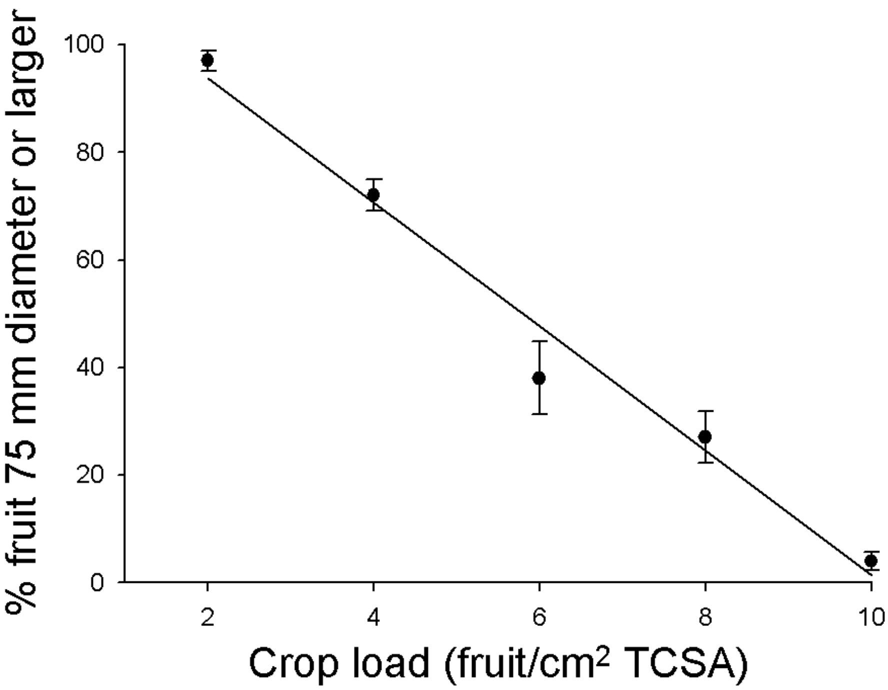


Figure 6.11*: The effect of crop load on fruit size of 'Delicious' apple. The equation of the line is:* y = 116.9 - 11.55x, R^2 = 0.97, P = 0.001

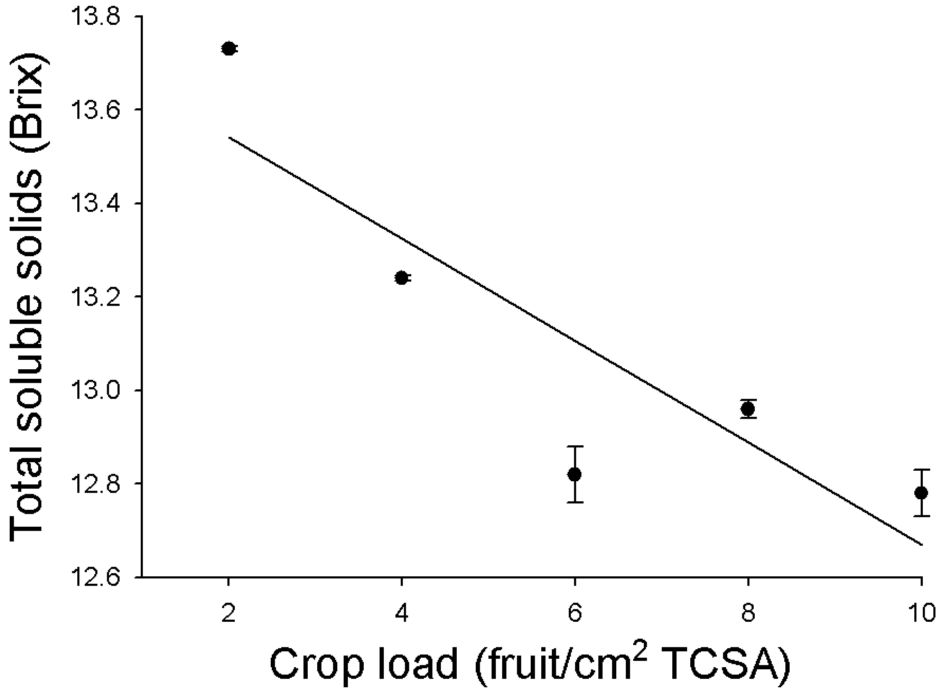


Figure 6.12: *The effect of crop load on fruit sugar content of 'Delicious' apple. The equation of the line is:* y = 13.76 - 0.109x, R^2 = 0.69, P = 0.05

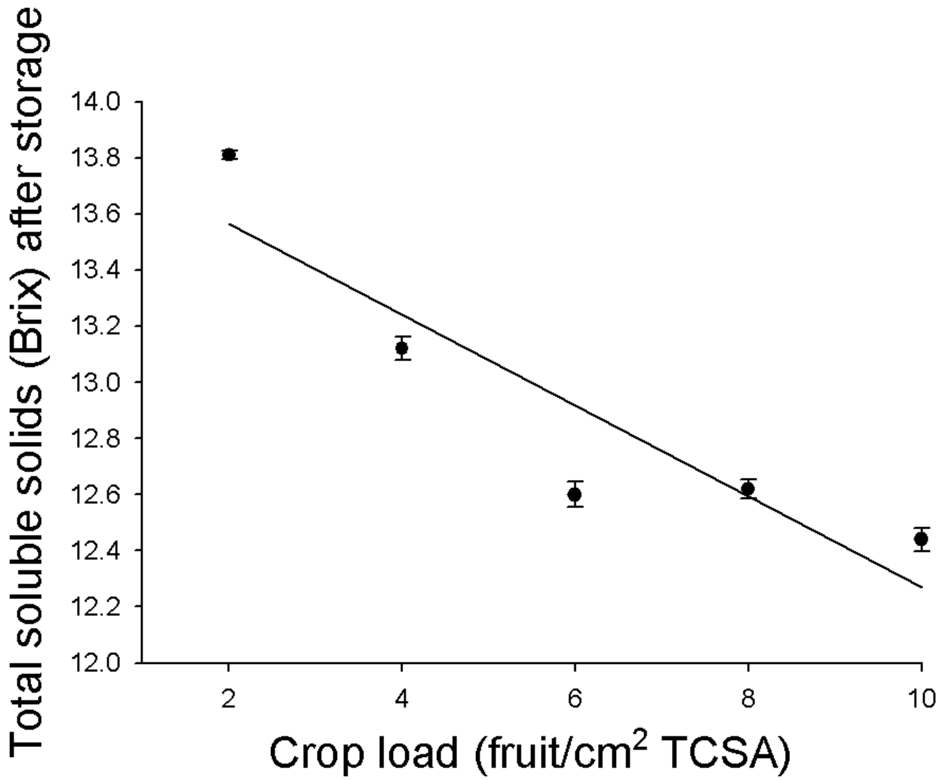


Figure 6.13: *The effect of crop load on fruit sugar content of 'Delicious' apple after cold storage. The equation of the line is:* y = 13.89 - 0.162x, R^2 = 0.78, P = 0.03

***Table 6.5**: The effect of crop load on fruit shape (length/diameter ratio), firmness and seed number of 'Delicious' apples hand-thinned 6 weeks after full bloom. TCSA, trunk cross-sectional area.*

Crop load	Fruit length/diameter ratio	Fruit flesh firmness (kg)	Number of seeds per fruit
2 fruit/cm^2 TCSA	0.984	11.18	6.0
4 fruit/cm^2 TCSA	0.983	10.64	5.2
6 fruit/cm^2 TCSA	0.969	10.25	5.9
8 fruit/cm^2 TCSA	0.973	10.47	5.8
10 fruit/cm^2 TCSA	0.977	10.28	6.3
LSD (P=0.05)	*ns*	*0.22*	*ns*

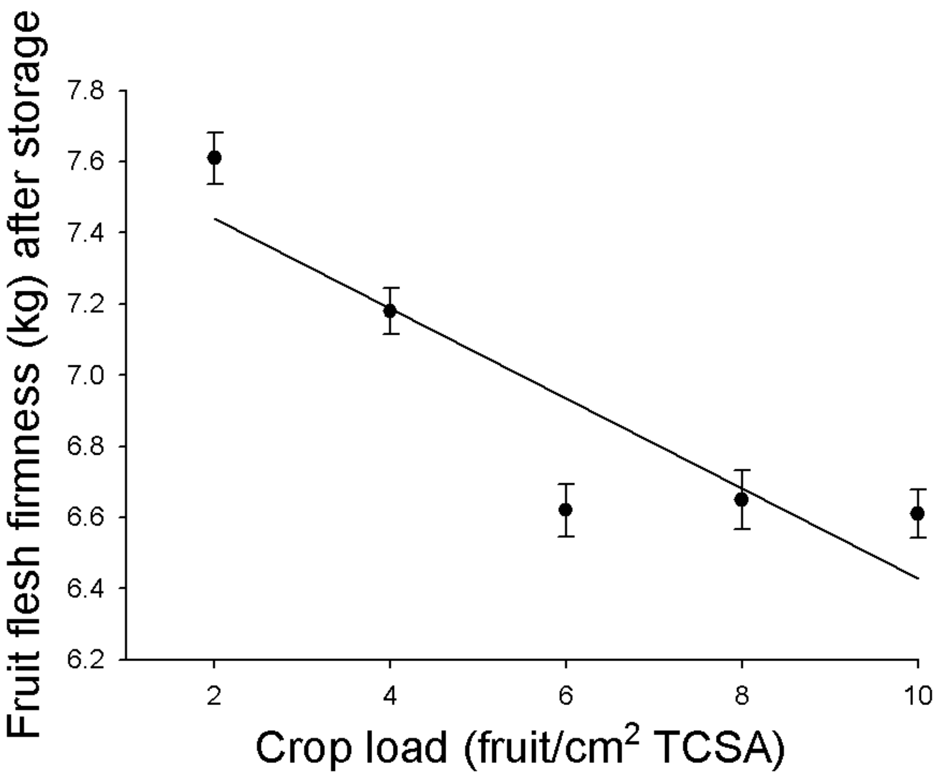


***Figure 6.14**: The effect of crop load on fruit flesh firmness of 'Delicious' apple after cold storage. The equation of the line is:* y = 7.693 - 0.1265x, R^2 = 0.73, P = 0.041

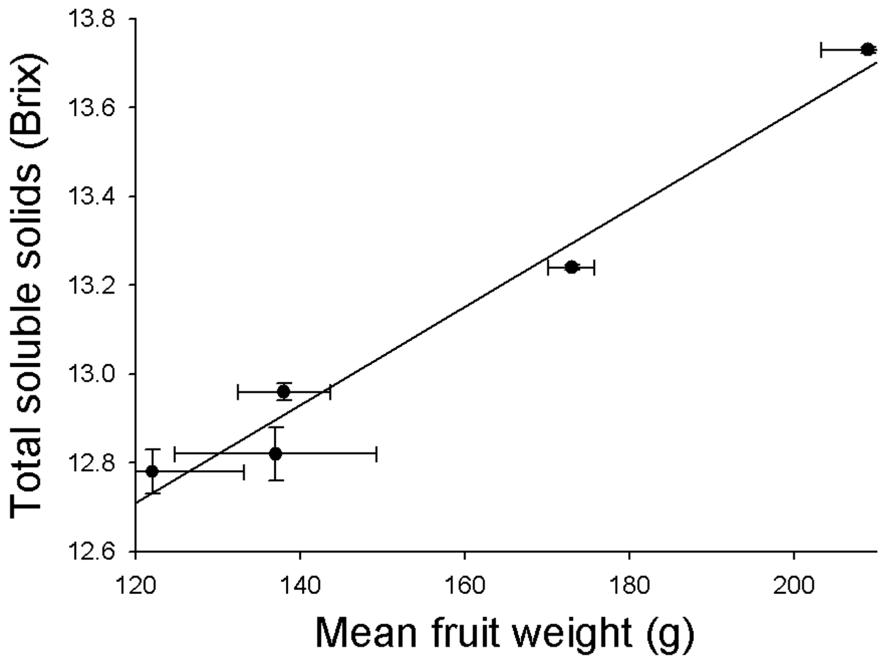


***Figure 6.15**: The relationship between fruit weight and sugar content of 'Delicious' apple. The equation of the line is:* y = 11.387 + 0.01103x, R^2 = 0.97, P = 0.002

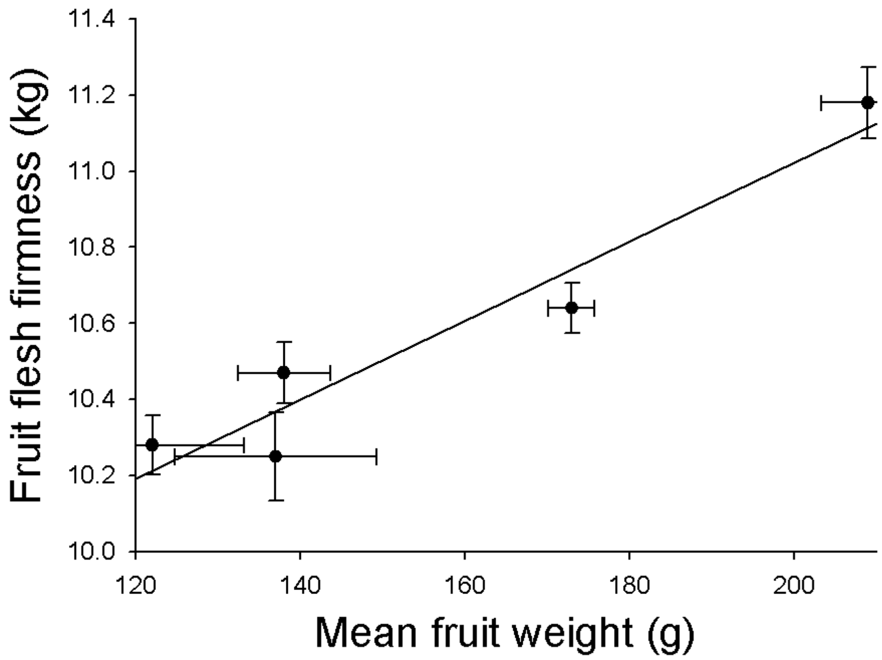


***Figure 6.16**: The relationship between fruit weight and firmness of 'Delicious' apple. The equation of the line is:* y = 8.947 + 0.01038x, R^2 = 0.90, P = 0.008

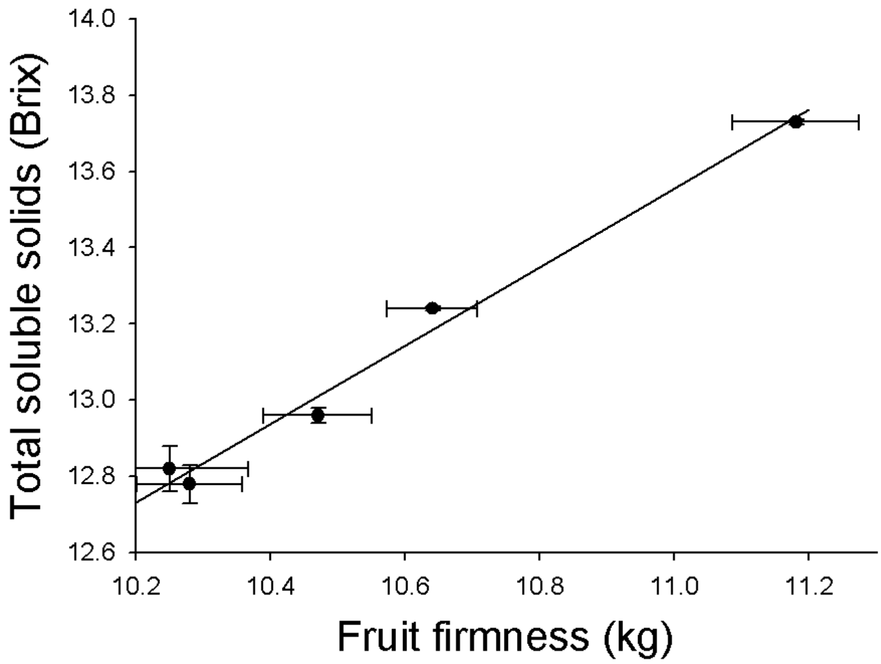


***Figure 6.17**: The relationship between fruit firmness and sugar content of 'Delicious' apple.*
The equation of the line is: y = 2.222 + 1.0303x, $R^2 = 0.98$, $P < 0.001$

3.4: Trial 4 - 'Delicious'

There were no significant interactions between crop load and time of thinning for mean fruit weight and return bloom (results not presented), but there were significant interactions for other parameters (Table 6.7).

Mean fruit weight was significantly higher at 3 fruit/cm^2 TCSA than at 6 fruit/cm^2 TCSA (Table 6.6(i)). Time of thinning also influenced mean fruit weight, with the later thinning times of 8, 12 or 16 wAFB producing significantly smaller fruit than trees thinned 1 wAFB (Table 6.6(ii)). Crop load had no significant effect on return bloom (Table 6.6(i)). Thinning at or later than 8 wAFB resulted in significantly lower return bloom than thinning at 1, 2 or 4 wAFB.

***Table 6.6**: The effect of crop load and time of thinning on mean fruit weight and return bloom of 'Delicious' apples. TCSA, trunk cross-sectional area; wAFB, weeks after full bloom.*

	Mean fruit Weight (g)	Return bloom (no. buds/cm^2 TCSA)
(i) Crop load		
3 fruit/cm^2 TCSA	170	14.1
6 fruit/cm^2 TCSA	144	13.3
LSD (P=0.05)	*10*	*ns*
(ii) Time of thinning		
1 wAFB	172	16.7
2 wAFB	161	15.4
4 wAFB	164	17.9
8 wAFB	147	10.5
12 wAFB	153	10.6
16 wAFB	149	11.3
LSD (P=0.05)	*18*	*3.5*

Fruit size (% fruit ≥ 75 mm diameter) was significantly higher at a crop load of 3 fruit/cm^2 TCSA than at 6 fruit/cm^2 TCSA at all thinning times, with the exception of 1 wAFB (Table 6.7). The treatments that produced the highest number of fruit ≥ 75 mm diameter were the two 1 wAFB treatments and 3 fruit/cm^2 TCSA thinned 2 or 4 wAFB.

Fruit L/D ratio was significantly lower in the 3 fruit/cm^2 TCSA treatment at 1 wAFB than the higher crop load (Table 6.7). At 8 and 12 wAFB, fruit L/D ratio was significantly lower at the higher crop load than the lower crop load. Fruit L/D ratio was statistically the same for the 3 fruit/cm^2 TCSA treatments at all thinning times, except for 1 wAFB.

Fruit TSS was significantly lower at the higher crop load compared with the lower crop load at all thinning times, except for 2 wAFB. At all thinning times, except for 8 wAFB, fruit firmness was significantly higher at 3 fruit/cm^2 TCSA than at 6 fruit/cm^2 TCSA. Trees thinned 16 wAFB produced significantly firmer fruit than all other treatments.

There were no significant treatment effects on the percentage of russet free fruit, % fruit with ≤ 10% russet, or number of seeds per fruit (results not presented).

***Table 6.7**: The interaction between crop load and time of thinning on fruit size (% fruit ≥ 75mm diameter), shape (length/diameter ratio), soluble solids content and firmness of 'Delicious' apples. TCSA, trunk cross-sectional area; wAFB, weeks after full bloom.*

No. fruit per cm^2 TCSA	Time of thinning (wAFB)	% fruit ≥ 75 mm diameter	Fruit length/diameter ratio	Total soluble solids content (°Brix)	Fruit flesh firmness (kg)
3	1	67	0.971	13.43	8.58
6	1	63	0.994	13.23	8.01
3	2	67	0.997	13.17	7.88
6	2	25	1.003	13.07	7.57
3	4	59	0.989	13.90	8.32
6	4	23	0.984	12.70	7.79
3	8	43	0.987	13.33	8.44
6	8	8	0.969	13.03	8.25
3	12	43	0.998	14.13	8.59
6	12	17	0.974	13.73	7.72
3	16	33	0.999	13.77	9.47
6	16	6	0.984	13.00	8.90
LSD (P=0.05)		*16*	*0.017*	*0.12*	*0.28*

3.5: Trial 5 - 'Pink Lady'

There were no interactions between crop load, time of thinning and rootstock for mean fruit weight, size or return bloom (results not presented). All three factors had a significant effect on mean fruit weight and the percentage of fruit ≥ 75 mm diameter, while rootstock and time of thinning, but not crop load, had a significant effect on return bloom (Table 6.8).

Trees on M26 rootstock produced significantly heavier fruit than those on MM106 (Table 6.8(i)). Fruit weight was significantly reduced at crop loads of 8 fruit/cm^2 TCSA compared with 4 or 6 fruit/cm^2 TCSA, while trees thinned at 10 and 14 wAFB produced significantly lighter fruit than trees thinned 2 or 6 wAFB (Table 6.8(ii)). Similar patterns were observed in the percentage of fruit ≥ 75 mm diameter for all three factors. Return bloom was significantly higher in trees on M26 rootstock than on MM106. Crop load had no significant effect on return bloom, but thinning 2 or 6 wAFB resulted in higher return bloom than at 10 or 14 wAFB.

Table 6.8: *The effect of rootstock, crop load and time of thinning on mean fruit weight, size (% fruit ≥ 75mm diameter), and return bloom of 'Pink Lady' apples. TCSA, trunk cross-sectional area; wAFB, weeks after full bloom.*

	Mean fruit weight (g)	% fruit ≥ 75 mm diameter	Return bloom (no. buds/cm^2 TCSA)
(i) Rootstock			
M26	166	30	13.9
MM106	156	24	5.3
LSD (P=0.05)	*5*	*2*	*1.3*
(ii) Crop load			
4 fruit/cm^2 TCSA	167	32	9.7
6 fruit/cm^2 TCSA	164	28	10.3
8 fruit/cm^2 TCSA	151	20	8.8
LSD (P=0.05)	*6*	*6*	*ns*
(iii) Time of thinning			
2 wAFB	169	36	10.7
6 wAFB	165	33	11.4
10 wAFB	156	18	8.8
14 wAFB	153	20	7.4
LSD (P=0.05)	*6*	*7*	*1.8*

There were significant interactions between the thinning treatments on other fruit quality parameters: fruit L/D ratio, TSS and firmness (Table 6.9). Although there were significant differences between treatments in L/D ratio, results showed no clear pattern with no consistent effects of rootstock, crop load or time of thinning.

Fruit TSS decreased with increasing crop load on M26 rootstocks on trees thinned 2 wAFB, and on MM106 rootstocks at 6 wAFB. Treatments with the highest TSS levels were 6 fruit/cm^2 TCSA at 6 wAFB and 10 wAFB on M26 rootstock. The treatment with the lowest TSS was 6 fruit/cm^2 TCSA at 10 wAFB on MM106. TSS levels were significantly higher on M26 rootstocks than in the corresponding MM106 treatments.

Fruit firmness was significantly higher in the 4 and 6 fruit/cm^2 TCSA 6 wAFB treatments on M26 than all other treatments. Increasing crop load resulted in a decrease in firmness at all thinning times on M26 rootstocks, but there were no distinct trends on MM106 stocks. Firmness was significantly higher on M26 rootstocks than in the corresponding MM106 rootstocks, except for the 8 fruit/cm^2 TCSA 2 and 6 wAFB treatments.

***Table 6.9**: The effect of rootstock, crop load and time of thinning on fruit shape (length/diameter ratio), sugar content and firmness of 'Pink Lady' apples. TCSA, trunk cross-sectional area; wAFB, weeks after full bloom.*

Root-stock	No. fruit per cm^2 TCSA	Time of thinning (wAFB)	Fruit length/diameter ratio	Total soluble solids content (°Brix)	Fruit flesh firmness (kg)
M26	4	2	0.936	15.96	8.96
M26	6	2	0.906	15.45	8.98
M26	8	2	0.941	15.18	7.99
M26	4	6	0.946	15.88	9.60
M26	6	6	0.934	16.35	9.53
M26	8	6	0.942	15.53	8.64
M26	4	10	0.964	16.07	9.10
M26	6	10	0.930	16.30	8.98
M26	8	10	0.934	16.18	8.56
M26	4	14	0.916	15.40	8.92
M26	6	14	0.917	15.23	8.55
M26	8	14	0.923	15.45	8.24
MM106	4	2	0.924	15.16	8.18
MM106	6	2	0.916	14.05	8.06
MM106	8	2	0.897	14.35	8.04
MM106	4	6	0.923	15.23	7.98
MM106	6	6	0.921	15.00	8.15
MM106	8	6	0.917	14.58	8.38
MM106	4	10	0.920	14.50	8.30
MM106	6	10	0.938	13.70	7.83
MM106	8	10	0.929	14.38	7.75
MM106	4	14	0.914	13.99	8.00
MM106	6	14	0.925	14.23	7.81
MM106	8	14	0.918	14.36	7.68
LSD (P=0.05)			*0.017*	*0.18*	*0.32*

3.6: Trial 6 - 'Gala'

There were significant interactions between treatments for all parameters assessed in 'Gala' (Table 6.10, 6.11), except for number of seeds (Table 6.12).

At 2 and 6 wAFB, mean fruit weight was significantly higher with crop loads of 3 or 6 fruit/cm^2 TCSA than with 9 fruit/cm^2 TCSA (Table 6.10). At 10 wAFB, a crop load of 3 fruit/cm^2 TCSA produced significantly heavier fruit than crop loads of either 6 or 9 fruit/cm^2 TCSA. There was no significant difference in mean fruit weight between the different crop loads at 14 wAFB.

Fruit size (percentage fruit ≥ 65 mm diameter) was significantly higher in trees thinned to 3 fruit/cm^2 TCSA 2 wAFB than any other treatment. At 2 wAFB, there was a significant reduction in fruit size with increasing crop load. In trees thinned 6 wAFB, there was no significant difference in fruit size at crop loads of 6 or 9 fruit/cm^2 TCSA, while there was no significant difference between the three crop loads at 10 and 14 wAFB.

Crop load had no significant effect on fruit shape (L/D ratio) at the earliest thinning timing. In the other contrasts, the lightest crop load resulted in higher L/D ratios than the heaviest crop loads. Return bloom was significantly higher at the lowest crop load than other treatments at 2, 6 and 10 wAFB.

Reducing crop load to 3 fruit/cm^2 TCSA produced fruit with the highest TSS compared with other treatments for the two earlier timings (Table 6.11). TSS levels decreased significantly from 3 to 6 fruit/cm^2 TCSA, except at 14 wAFB. Fruit firmness was significantly lower in fruit thinned 2 wAFB than later thinned fruit.

Starch levels were lower in trees thinned to 3 fruit/cm^2 TCSA at 2 wAFB, but this pattern was reversed at 6 and 14 wAFB. There was no significant difference between crop loads in starch levels at 10 wAFB. The general trend was for starch levels to be higher with later thinning.

There were significant differences between treatments in fruit background colour, with fruit from the highest crop load treatments at 2, 6 and 10 wAFB being greener than the two lighter crop loads at these timings. For treatments applied 14 wAFB, a crop load of 6 fruit/cm^2 TCSA produced the greenest fruit

***Table 6.10**: The effect of crop load and time of thinning on mean fruit weight, size (% fruit ≥ 65 mm diameter), shape (length/diameter ratio) and return bloom of 'Gala' apples. TCSA, trunk cross-sectional area; wAFB, weeks after full bloom.*

No. fruit per cm^2 TCSA	Time of thinning (wAFB)	Mean fruit weight (g)	% fruit ≥ 65 mm diameter	Fruit length/diameter ratio	Return bloom (no. buds/cm^2 TCSA)
3	2	148	37	0.928	19.7
6	2	138	16	0.929	9.1
9	2	118	2	0.915	10.6
3	6	140	11	0.934	18.5
6	6	125	4	0.933	11.5
9	6	95	0	0.908	8.2
3	10	133	7	0.942	12.1
6	10	94	1	0.904	5.0
9	10	98	0	0.894	7.9
3	14	104	0	0.913	5.4
6	14	95	0	0.887	7.7
9	14	88	0	0.892	3.9
LSD (P=0.05)		*17*	*10*	*0.015*	*6.7*

***Table 6.11**: The effect of crop load and time of thinning on fruit sugar content, firmness, starch index and background skin colour of 'Gala' apples. TCSA, trunk cross-sectional area; wAFB, weeks after full bloom.*

No. fruit per cm^2 TCSA)	Time of thinning (wAFB)	Total soluble solids (°Brix)	Fruit flesh firmness (kg)	Starch index	Background skin colour
3	2	15.38	8.16	4.0	4.5
6	2	14.50	8.67	3.4	4.5
9	2	14.50	8.40	3.6	4.1
3	6	15.15	9.26	2.9	4.2
6	6	14.69	8.85	3.4	4.5
9	6	14.18	9.60	3.6	3.6
3	10	14.44	9.17	2.7	4.5
6	10	13.90	9.28	2.9	4.2
9	10	15.20	9.73	2.9	3.3
3	14	14.23	10.20	1.9	4.5
6	14	14.60	9.63	2.3	3.2
9	14	13.85	9.47	2.4	4.2
LSD (P=0.05)		*0.14*	*0.32*	*0.3*	*0.3*

Fruit from trees with crop loads of 9 fruit/cm^2 TCSA had higher seed numbers than crop loads of 6 fruit/cm^2 TCSA (Table 6.12(i)). Time of thinning also affected seed number, with significantly higher seed numbers in fruit from trees thinned 2 wAFB than in trees thinned later.

***Table 6.12**: The effect of crop load and time of thinning on average seed number of 'Gala' apples. TCSA, trunk cross-sectional area; wAFB, weeks after full bloom.*

	Average number of seeds per fruit
(i) Crop load	
3 fruit/cm^2 TCSA	6.8
6 fruit/cm^2 TCSA	6.5
9 fruit/cm^2 TCSA	7.0
LSD (P=0.05)	*0.3*
(ii) Time of thinning	
2 wAFB	7.3
6 wAFB	6.6
10 wAFB	6.5
14 wAFB	6.7
LSD (P=0.05)	*0.3*

4. Discussion

From these data both crop load and time of thinning play an important role in determining fruit quality at harvest, however there were differences between cultivars in optimum crop load and the effect of thinning time. While trends were similar in the two 'Fuji' trials conducted in consecutive years, there were considerable differences in the actual figures obtained for each parameter studied. This suggests that while crop load has a major influence, climatic differences between years (Appendix 3) can result in a shift in actual values obtained possibly through date and spread of flowering, pollination and early growth of fruit.

Fruit weight and size

As expected, for all cultivars studied, individual mean fruit weight was reduced with increasing crop load over the range of crop loads examined in this study. Time of thinning also heavily influenced fruit weight and size, confirming the postulation by Link (2000) that, as the supply of carbon available to the fruit may be limited by competition from other fruits, a marked influence of time of thinning on fruit size would be expected.

In ‘Fuji’, crop loads of 2-4 fruit/cm^2 TCSA achieved fruit weights of 200 g per fruit in one year, however in the second year this fruit weight was only achieved at the lower crop load level of 2 fruit/cm^2 TCSA. Jones *et al*. (1992b) suggested that weights of 200 g per fruit were readily achievable with crop loads of 4-6 fruit/cm^2 TCSA, however they also recommended thinning at blossom time, rather than post-bloom. Setting target crop loads of 5-7 fruit/cm^2 TCSA, Bound *et al*. (1993b) obtained fruit weights of around 200 g per apple with more than 40% of the fruit larger than 80 mm diameter, following chemical thinning with ethephon and BA within 3 weeks of FB. However, BA has been demonstrated to increase fruit size even in the absence of any thinning (McLaughlin and Greene 1984; Greene *et al*. 1990). The lower weights achieved in this study at 4 or 6 fruit/cm^2 TCSA are most likely the result of delaying thinning to 6 weeks after flowering, leading to loss of fruit size through competition with fruit that was later removed. According to Jones *et al*. (1992b), delaying thinning can result in a loss of as much as 10 g per fruit for every week delay in thinning. Koike *et al*. (2003) concluded that primary thinning of ‘Fuji’ should be performed within 28 dAFB to ensure good fruit size. The present results suggest that for ‘Fuji’ thinned at 6 wAFB, crop loads should be reduced to 2-4 fruit/cm^2 TCSA in order to achieve fruit weights of 200 g.

In ‘Delicious’, weights of at least 150 g per fruit were achieved at crop loads of 2-4 fruit/cm^2 TCSA. However, crop loads of 6-10 fruit/cm^2 TCSA produced fruit weights in the order of 125-145 g. Following application of NAA and ethephon during the bloom period, Koen *et al*. (1988) concluded that 2-4 fruit/cm^2 TCSA is an ideal target range crop load for ‘Delicious’. The results presented in this study demonstrate that this target range is also applicable when hand thinning is performed as late as 6 wAFB.

There are currently no recommendations available for target crop loads for ‘Pink Lady’ or ‘Gala’. Results from this study suggest that in both ‘Pink Lady’ and ‘Gala’, fruit weight and size start to decline with crop loads greater than 6 fruit/cm^2 TCSA.

The results of this study support the conclusion of Jones *et al*. (1992b) and McArtney *et al*. (1996) that earlier thinning can result in a very large improvement in mean fruit weight. Working with ‘Empire’, Lakso *et al*. (2001) concluded that effective hand thinning for size increases could be done as late as 20 dAFB, but that even thinning at 40 dAFB gave a clear increase in final fruit size compared with no thinning. These authors also reported that application of NAA, BA and carbaryl at 15 days after bloom all inhibited fruit growth too much to allow maximum response to crop reduction. While flower thinning is highly desirable, this is not practical with hand thinning, however it would appear that high fruit weights can be achieved for most cultivars at relatively high crop loads if thinning is completed as soon after flowering as possible. If thinning is delayed crop loads need to be reduced in order to achieve these weights, resulting in reduced yield, which is a function of number and size of the fruit on the tree.

Rootstocks affect apple fruit quality by influencing both tree vigour and crop load. At similar crop loads, trees on M26 rootstocks in this study produced heavier fruit than on the more vigorous MM106 rootstocks for ‘Pink Lady’. The increased fruit size on the weaker M26 rootstock conflicts with the findings of Fallahi and Simons (1995) and Riesen and Husistein (1998). However, these authors were comparing a range of dwarfing rootstocks and did not include any semi-vigorous or vigorous rootstocks in their studies.

Fruit shape

In this study, thinning influenced fruit shape in some cultivars but not others. In those cultivars where there was an effect, higher crop loads generally produced flatter fruit. This is in agreement with the conclusions of Link (2000) that thinning normally favours fruit development. However it appears from the present study that fruit shape may also be influenced by time of thinning in some cultivars, particularly 'Delicious' where thinning close to bloom reversed this trend towards flatter fruit. As previously discussed, fruit shape and typiness are very important in 'Delicious' and anything that flattens the apple could disadvantage the fruit in the market (Williams and Stahly 1969; Unrath 1974; Veinbrandts 1979; Veinbrandts and Miller 1981).

Total soluble solids

For most cultivars, fruit soluble solids content decreased with increasing crop load. This agrees with the findings of Koike *et al*. (2003) who reported a 14% increase in sugar levels in 'Fuji' fruit from hand-thinned trees compared with un-thinned trees. Johnson (1995) also reported a similar effect for hand-thinned 'Cox's Orange Pippin'. However, in the 'Fuji' and 'Delicious' trials that were thinned 6 wAFB, there was a positive correlation between sugar content and fruit weight, suggesting that early thinning can maintain fruit sugar levels in larger fruit.

A rootstock effect was observed in 'Pink Lady', with lower soluble solids on the more vigorous MM106 rootstocks. Fallahi and Simons (1995) also reported that soluble solids at harvest were lower in fruit from trees on M26 rootstocks compared with the more dwarfing M27 and M9 rootstocks. These trends suggest that the rootstock effect may be related to tree vigour, with higher soluble solids in less vigorous trees. This leads to the assumption that less assimilate is used for vegetative growth in the more dwarfing trees.

Firmness

For the cultivars 'Fuji', 'Delicious' and 'Pink Lady' fruit firmness decreased with increasing crop load, supporting the results of Garriz *et al.* (2000) who found that fruit flesh firmness was significantly lower in 'Braeburn' trees carrying high crop loads than in trees with moderate or low crop loads. Jones *et al*. (1997b) also reported increased firmness with reduced crop load following chemical thinning of 'Pink Lady' and 'Jonagold' with ethephon and BA. Link (2000) suggested that the reduced firmness often observed in heavily cropped trees could be due to carbohydrate supply for cell wall synthesis becoming limited. In this study, ‘Gala’ showed no clear trends relating firmness to crop load, but there was an effect with time of thinning, with thinning close to bloom producing softer fruit than trees thinned from 6 weeks after bloom. A possible explanation for this result is that early thinning causes fruit to mature earlier than later thinning, particularly when combined with the increased soluble solids observed in early thinned fruit.

An unexpected finding from this work was the positive relationship in both ‘Fuji’ and ‘Delicious’ between fruit firmness and mean fruit weight, and between sugar content and firmness in early thinned fruit. This study provides evidence that early thinning has a major role to play in fruit quality considerations. Previous correlations of fruit softness with high TSS in large fruit are based on concepts of the contrast between vigorously growing off-year trees compared with less vigorous on-year trees. In this study, early-thinned regular bearing trees produced large fruit that were firmer and with higher TSS than later thinned fruit. Not only does this finding conflict with current thoughts on firmness, sugar content and fruit size, but it demonstrates additional advantages for early thinning beyond fruit size. It also shows that large fruit can be of better quality than small fruit, providing it is from regular bearing or on-year trees where the fruit was thinned early.

Rootstock influenced fruit firmness in ‘Pink Lady’, with no relationship between firmness and crop load being observed on MM106 rootstocks, however fruit firmness was higher on M26 rootstocks than on MM106. Differences in firmness of ‘Arlet’ and ‘Fiesta’ fruit from trees with different rootstocks were also observed by Riesen and Husistein (1998). These authors suggested that these softer fruit, which also had higher sugar levels, were the result of advanced fruit maturity on some rootstocks. While this is a logical conclusion, ‘Pink Lady’ in this study produced softer fruit with lower sugar content on MM106 rootstocks. As these fruit were also smaller than fruit from M26 rootstocks, this result is difficult to explain, as the expectation would be that fruit from MM106 rootstocks should be firmer. If fruit from MM106 rootstocks contained fewer and larger cells that those from M26 rootstocks, this would explain the difference in fruit firmness between the two rootstocks.

Seeds

In general, crop load had no affect on fruit seed numbers, and where there were treatment effects, the differences between treatments were small and not consistent with treatment.

Starch

Starch levels were examined in only one cultivar, ‘Gala’. While there was no crop load effect, time of thinning did influence starch levels. The earlier that thinning was undertaken, the less starch present. This is most likely associated with fruit maturity, particularly when examined in conjunction with fruit soluble solids content, as earlier thinned fruit also had higher soluble solids than later thinned fruit. This evidence supports the findings of Johnson (1995) who reported that earlier maturation of fruits from trees thinned 5 dAFB was indicated by increased internal ethylene concentration and respiration rate, and a shorter delay to ethylene production. Johnson suggested that early thinning can advance fruit maturity by up to 16 days. He also stated that the rate of starch and firmness decline, and increase in TSS are unsuitable to measure the effects of thinning on fruit maturity, since fruits from thinned trees are firmer and higher in TSS than those from un-thinned trees.

Return bloom

Time of thinning was important for return bloom, with thinning later than 6 weeks after bloom reducing return bloom in the three cultivars ‘Delicious’, ‘Pink Lady’ and ‘Gala’. Although return bloom was not assessed on the cultivar ‘Fuji’ in this study, Jones *et al*. (1992b) reported a decline in return bloom at 8 weeks after bloom, and Koike *et al*. (2003) demonstrated the importance of thinning before 4 wAFB to ensure return bloom of ‘Fuji’.

Rootstock had an influence on return bloom in ‘Pink Lady’, with return bloom tripled on trees with M26 rootstocks compared with MM106 rootstocks.

Chapter 7

Controlling crop load with desiccants

1. Introduction

While reducing crop load by hand can improve fruit size and quality if carried out early enough (Chapter 6), hand thinning is expensive and impractical during flowering and early fruit development. Hence in commercial orchards the only way to economically reduce crop load at or soon after flowering is with the use of chemicals applied during the blossom period and up to 4-5 weeks after flowering (Jones *et al*. 1998).

The history of chemical thinning has been chequered, with different chemicals finding favour at different times (Bound 2001b), or chemical products being removed from the market for various reasons. Following the removal of DNOC in the USA in 1989, growers were left with very limited options for thinning (Williams *et al*. 1995). This highlighted the importance of having a range of options for thinning, rather than being reliant on one chemical.

Although there are two chemicals registered in Australia as blossom thinners (NAA and ethephon), the efficacy of these thinners is dependent on weather conditions, particularly temperature, at the time of application and the period following application (Jones and Koen 1985; Stover 1992). This means that it can be difficult to achieve consistency with these thinners during the unpredictable spring weather experienced in most Australian apple growing regions. An added complication in assessing the efficacy of chemicals as thinning agents is the variation in flowering habit of many apple cultivars. The older cultivars such as ‘Delicious’, ‘Granny Smith’ and ‘Sturmer’ tend to have a relatively short flowering period of 1-2 weeks compared with some of the newer cultivars such as ‘Gala’, ‘Fuji’, ‘Pink Lady’ and ‘Sundowner’, which flower over a period of 3-6 weeks under Australian conditions (Jotic, personal communication).

The widespread resurgence of interest, over the last 15 years, in the use of desiccating chemicals as thinning agents may provide alternatives and a solution to the problem of temperature dependency. Desiccants act by burning the style and stigma, thus preventing fertilisation. Because of their mode of action, desiccants are less likely to be dependent on temperature conditions for their effectiveness and hence may be more predictable in their thinning action in areas with cooler conditions during flowering.

Desiccating compounds trialed on apples include ATS (Irving *et al.* 1989; Byers 1997; Bound and Jones 2004); Wilthin™ (Williams 1993; Andrews and Collier 1995; Byers 1997); endothal (Williams *et al.* 1995; Bound and Jones 1997; Byers 1997); pelargonic acid (Byers 1997; McArtney *et al*. 2002); YI-1066 (Byers 1997) and lime sulphur, sodium chloride and calcium chloride (McArtney *et al*. 2002).

While many authors have reported the thinning effects of desiccants, their impact on fruit quality has rarely been reported. Bound and Jones (1997) and Bound (2001a) have described the effect of endothal on fruit shape, skin finish, seed numbers, fruit sugar content and fruit firmness, and Ferree and Schmid (2001) examined the effect of endothal on skin finish. Byers (1997) discussed the impact of endothal, pelargonic acid, YI-1066, Wilthin and ATS on fruit skin finish, while Bound and Jones (2004) assessed the effect of ATS on apple fruit shape, skin finish and seed numbers. Bound and Jones (2004) reported that rates of ATS of 3.0% or higher caused high levels of foliar damage and bud death. Damage that results in loss of leaf area can be critical, as the results discussed in Chapter 8 suggest that a reduction in carbohydrate assimilation during the cell division phase of fruit development is likely to affect fruit size and quality.

As further information on the efficacy of ATS and its effect on fruit quality was required, the work presented in Part 1 of this chapter was an extension of an earlier evaluation of ATS as a thinning agent (Bound and Jones 2004) not included in this thesis. With the optimal concentration and number of applications for thinning with

ATS determined, the impact of ATS on fruit quality could be examined in more detail.

Australian growers generally use a thinning program consisting of both bloom and post-bloom thinners to reduce the risk of over- or under-thinning (Jones *et al*. 1998). Therefore, to determine whether ATS was compatible in a thinning program with post-bloom thinners, these studies included an assessment of ATS with a post-bloom thinner. Of the two post-bloom thinners registered in Australia, the thinner chosen for this study was BA, as carbaryl (1-naphthyl-N-methylcarbamate), is a persistent pesticide that has been reported in orchard ground, or runoff, water in Tasmania (Wilson personal communication), and is toxic to bees and mammals (Tomlin 1994).

As ATS has been shown to be an effective thinner, it is reasonable to assume that other chemicals in the thiosulphate group could also have a thinning action. Potassium thiosulphate (KTS) is used as a fertiliser and is available in a liquid formulation from agricultural suppliers. Therefore, the studies reported in Part 2 of this chapter set out to assess the effectiveness of KTS as an alternative blossom thinner and also to determine its effect on fruit quality.

2. Ammonium thiosulphate and 6-benzyladenine

Initial application rates for ATS used in this study were based on the results of Bound and Jones (2004). As this previous work examined single applications at 20% bloom, 50% bloom or 80% bloom, the earlier timings were combined with the later timing to give double applications at either 20 & 80% bloom or 50 & 80% bloom in the first trial reported here. These double applications were compared with a single application at 80% bloom. Further trials examined triple applications of ATS, and ATS in a program with the post-bloom thinner BA.

2.1: Materials and methods

Four trials were established at various sites in the Huon Valley on mature regular bearing ‘Delicious’ trees over three consecutive seasons. Trial 1 was established on 11-year-old Hi-Early ‘Delicious’ trees at Cygnet. The following season two trials were established, one on 10-year-old Oregon Spur ‘Delicious’ trees at Grove (trial 2) and the other on 9-year-old Hi-Early ‘Delicious’ trees at Cradoc (trial 3). Trial 4 was established in the third season on 10-year-old Hi-Early ‘Delicious’ trees at Cradoc. Trees in trials 1, 3 and 4 were approximately 3 m in height, trained to a central axis system, with a spacing of 4 m between rows and 3 m within the row. Trees in trial 2 were approximately 2.2 m in height, trained to a central axis system, with a spacing of 4 m between rows and 2 m within the row.

Apart from thinning, all trees were subjected to commercial orchard management practices, including irrigation, and pest and disease management.

Trial design

Trees were blocked into blossom density groups and treatments allocated at random to single tree plots within each block for trials 1 and 2, giving four replicates per treatment. The same blocking system but with five replicates was used in trials 3 and 4.

Treatments

An unsprayed control treatment and a treatment hand thinned at 4 wAFB were included in all trials.

Trial 1 (Hi-Early ‘Delicious’): ATS (58% a.i.) (photographic grade formulation) was applied as a single 80% bloom application at 0.5, 0.75, 1.0, 1.25 or 1.5% v/v, either alone or followed by the post-bloom thinner CyLex (2% 6-benzyladenine, Abbott Laboratories) at 150 ppm applied 3 wAFB. In addition rates of 0.5, 1.0 or 1.5% ATS were applied as a double application at either 20 & 80% bloom, or 50 & 80% bloom.

Trial 2 (Oregon Spur 'Delicious'): four rates of ATS (0.8, 1.0, 1.2 or 1.4% v/v) were applied as either a single application at 20% bloom; double application at 20 & 80% bloom; triple application at 20 & 80% bloom & 3 dAFB; or double application as above followed by 150 ppm CyLex 3 wAFB. As well as including an untreated control, the industry standard treatments of 80 ppm ethephon at FB, and ethephon followed by 150 ppm CyLex applied 3 wAFB were included to allow a comparison with common commercial treatments (Jones *et al*. 1998). CyLex was also applied as a single application at 3 wAFB to ascertain its thinning effect when used alone.

Trial 3 (Hi-Early 'Delicious'): 0.8, 1.0 or 1.2% v/v ATS was applied as a double application at 20 & 80% bloom, with or without 150 ppm CyLex 3 wAFB.

Trial 4 (Hi-Early 'Delicious'): two rates of ATS (1.0 or 1.2% v/v) were applied as either a single application at 20% bloom; double application at 20 & 80% bloom; triple application at 20 & 80% bloom & 3 dAFB; or double application as above followed by 150ppm CyLex 3 wAFB.

Spray application

All sprays were applied with an hydraulic hand lance. Ethephon and ATS were applied at a spray volume of 2,500 L/ha, and CyLex at the recommended label volume of 1,200 L/ha. The wetting agent Tween 20 (polyoxyethylene sorbitan monolaurate) was included at the rate of 1.25 ml/L with all thinning chemicals.

Assessments

Blossom density was assessed in early October. Fruit was harvested at normal commercial harvest time in March of each year. In trial 2 total numbers of fruit per tree were counted and weighed. For trials 1, 3 and 4 the numbers and weight of fruit were recorded separately for each marked limb and for the rest of the tree. Number of fruit/100 blossom clusters, number of fruit/cm^2 TCSA, and mean fruit weight were calculated for all trials as described in Chapter 3.

Fruit was graded, and number of fruit ≥ 70 mm diameter determined in all trials. Samples were assessed for L/D ratio, TSS, firmness and seed number as described in Chapter 3. Fruit samples were examined for russet in trial 1. In trial 2, TSS and firmness were also assessed on fruit samples that had been stored at 1°C for 3 months. Return bloom was determined as described in Chapter 3.

Data analysis

Data were analysed by analysis of variance as described in Chapter 3. Linear regressions showing relationships between some quality attributes and fruit load or size across all treatments were also plotted.

2.2: Results

Trial 1 - Hi-Early 'Delicious'

At 80% bloom, ATS had no significant thinning effect, except at the highest concentration of 1.5% (Table 7.1). Addition of CyLex to the program showed no increase in thinning. There was no significant difference between applying one or two applications of ATS, but compared with the control, two applications thinned significantly at 1.0 and 1.5% whereas one application only thinned at 1.5%. The two successful double applications achieved similar thinning to the hand-thin treatments, which represented a reasonable crop load for these trees. The only treatment to achieve crop loads within the target range for both variables was 1.5% ATS at 20 & 80% bloom. There was no effect on return bloom.

Both fruit weight and size (Table 7.2) were significantly improved by a number of treatments compared with the control. Two applications of 1.5% ATS resulted in significantly increased fruit weight and size compared with the corresponding single application. Addition of CyLex at this concentration significantly improved fruit weight and size. While no treatments achieved target levels, several treatments showed the same results as the hand-thinned treatment. These were 1.0% ATS at

80% bloom; 1.0 and 1.5% ATS plus CyLex; 1.0 and 1.5% ATS at 20 & 80% bloom; and 1.5% ATS at 50 & 80% bloom.

Table 7.1*: The effect of ammonium thiosulphate (ATS) and CyLex on crop load and return bloom of Hi-Early 'Delicious' apples (Trial 1). TCSA, trunk cross-sectional area; wAFB, weeks after full bloom. CyLex applied 3 wAFB at 150 ppm.*

	No. fruit per 100 blossom clusters	No. fruit per cm^2 TCSA	Return bloom (buds/cm^2 TCSA)
Control	121	10.41	5.9
Hand-thin 4 wAFB	65	5.58	7.5
0.5% ATS @ 80% bloom	120	11.18	3.8
0.75% ATS @ 80% bloom	90	6.96	5.3
1.0% ATS @ 80% bloom	101	7.72	6.3
1.25% ATS @ 80% bloom	92	6.95	6.6
1.5% ATS @ 80% bloom	77	5.08	5.9
0.5% ATS @ 80% bloom + CyLex	119	9.12	7.1
0.75% ATS @ 80% bloom + CyLex	119	9.29	5.4
1.0% ATS @ 80% bloom + CyLex	94	7.39	5.5
1.25% ATS @ 80% bloom + CyLex	109	9.48	4.6
1.5% ATS @ 80% bloom + CyLex	82	7.08	6.9
0.5% ATS @ 20 & 80% bloom	109	7.82	6.3
1.0% ATS @ 20 & 80% bloom	70	4.83	6.6
1.5% ATS @ 20 & 80% bloom	49	3.28	5.7
0.5% ATS @ 50 & 80% bloom	91	8.11	7.9
1.0% ATS @ 50 & 80% bloom	86	7.13	6.3
1.5% ATS @ 50 & 80% bloom	60	5.29	6.1
LSD (P=0.05)	*37*	*3.58*	*ns*
Commercial target levels	*40-60*	*2-4*	

Compared with the control, three treatments significantly reduced TSS (0.5% ATS at 80% bloom with and without CyLex and 1.25% ATS at 80% bloom with CyLex) (Table 7.3). Several treatments significantly increased soluble solids: these were 0.75% and 1.5% applications at 80% bloom, 1.5% ATS + CyLex, 0.5% and 1.5% ATS at 20 & 80% bloom, and the 1.0% and 1.5% ATS at 50 & 80% bloom. The only significant treatment effect on fruit firmness was an increase in response to 1.0% ATS at 20 & 80% bloom.

***Table 7.2**: The effect of ammonium thiosulphate (ATS) and CyLex on mean fruit weight and fruit size (% fruit ≥ 70 mm diameter) of Hi-Early 'Delicious' apples (Trial 1). wAFB, weeks after full bloom. CyLex applied 3 wAFB at 150 ppm.*

	Mean fruit weight (g)	% fruit ≥ 70 mm diameter
Control	103	10
Hand-thin 4 wAFB	141	54
0.5% ATS @ 80% bloom	107	11
0.75% ATS @ 80% bloom	112	21
1.0% ATS @ 80% bloom	126	34
1.25% ATS @ 80% bloom	118	20
1.5% ATS @ 80% bloom	104	11
0.5% ATS @ 80% bloom + CyLex	113	18
0.75% ATS @ 80% bloom + CyLex	120	23
1.0% ATS @ 80% bloom + CyLex	126	33
1.25% ATS @ 80% bloom + CyLex	113	17
1.5% ATS @ 80% bloom + CyLex	129	38
0.5% ATS @ 20 & 80% bloom	115	21
1.0% ATS @ 20 & 80% bloom	144	54
1.5% ATS @ 20 & 80% bloom	133	41
0.5% ATS @ 50 & 80% bloom	114	18
1.0% ATS @ 50 & 80% bloom	108	13
1.5% ATS @ 50 & 80% bloom	137	49
LSD (P=0.05)	*18*	*20*
Commercial target levels	*150*	*75*

***Table 7.3**: The effect of ammonium thiosulphate (ATS) and CyLex on fruit soluble solids and flesh firmness of Hi-Early 'Delicious' apples (Trial 1). wAFB, weeks after full bloom. CyLex applied 3 wAFB at 150 ppm.*

	Total soluble solids (ºBrix)	Fruit flesh firmness (kg)
Control	12.90	10.59
Hand-thin 4 wAFB	13.54	11.33
0.5% ATS @ 80% bloom	12.47	10.07
0.75% ATS @ 80% bloom	13.55	10.79
1.0% ATS @ 80% bloom	13.02	10.61
1.25% ATS @ 80% bloom	13.15	11.05
1.5% ATS @ 80% bloom	13.57	11.21
0.5% ATS @ 80% bloom + CyLex	12.28	11.25
0.75% ATS @ 80% bloom + CyLex	12.77	11.37
1.0% ATS @ 80% bloom + CyLex	12.87	10.96
1.25% ATS @ 80% bloom + CyLex	12.57	10.93
1.5% ATS @ 80% bloom + CyLex	13.35	10.89
0.5% ATS @ 20 & 80% bloom	13.62	10.48
1.0% ATS @ 20 & 80% bloom	12.97	12.28
1.5% ATS @ 20 & 80% bloom	13.82	11.12
0.5% ATS @ 50 & 80% bloom	12.92	11.07
1.0% ATS @ 50 & 80% bloom	14.15	10.62
1.5% ATS @ 50 & 80% bloom	13.33	11.12
LSD (P=0.05)	*0.25*	*0.91*

Fruit length/diameter ratio was not affected by treatment (Table 7.4).

Seed numbers (Table 7.4) were significantly reduced by both the 1.0% ATS at 80% bloom and 1.0% ATS followed by CyLex treatments. There was a treatment effect on russet, with 1.5% ATS at 20 & 80% bloom causing a significant reduction in the percentage of russet-free fruit compared with the control.

***Table 7.4**: The effect of ammonium thiosulphate (ATS) and CyLex on fruit shape (length/diameter ratio), seed number, and skin finish of Hi-Early 'Delicious' apples (Trial 1). wAFB, weeks after full bloom. CyLex applied 3 wAFB at 150 ppm.*

	Fruit length/diameter ratio	Average no. seeds per fruit	% russet-free fruit (export quality)
Control	0.905	5.4	79
Hand-thin 4 wAFB	0.930	4.6	68
0.5% ATS @ 80% bloom	0.917	5.0	84
0.75% ATS @ 80% bloom	0.897	4.8	68
1.0% ATS @ 80% bloom	0.898	4.2	81
1.25% ATS @ 80% bloom	0.998	4.6	82
1.5% ATS @ 80% bloom	0.908	5.2	65
0.5% ATS @ 80% bloom + CyLex	0.920	4.9	88
0.75% ATS @ 80% bloom + CyLex	0.917	5.1	75
1.0% ATS @ 80% bloom + CyLex	0.913	4.2	73
1.25% ATS @ 80% bloom + CyLex	0.913	6.3	81
1.5% ATS @ 80% bloom + CyLex	0.919	4.4	63
0.5% ATS @ 20 & 80% bloom	0.887	5.2	65
1.0% ATS @ 20 & 80% bloom	0.897	4.9	73
1.5% ATS @ 20 & 80% bloom	0.891	5.5	51
0.5% ATS @ 50 & 80% bloom	0.915	4.7	81
1.0% ATS @ 50 & 80% bloom	0.911	4.6	68
1.5% ATS @ 50 & 80% bloom	0.882	4.8	65
LSD (P=0.05)	*ns*	*0.9*	*19*

Trial 2 - Oregon Spur 'Delicious'

All treatments significantly reduced the number of fruit/cm^2 TCSA compared with the control (Table 7.5). Most treatments (except for the single 1.0% ATS application) reduced the number of fruit/100 blossom clusters compared with the control. All contrasts showed that a double application of ATS thinned more than a single application at all concentrations. Addition of a third application 1 wAFB increased thinning further in three out of four treatments with respect to number of fruit/cm^2 TCSA. The higher rates of ATS mostly resulted in a significant increase in thinning compared with the lower rates. Addition of CyLex to the program after a double application of ATS achieved similar thinning levels to three ATS applications. Target thinning levels were achieved by triple application of ATS at the higher rates, and the CyLex treatments.

Compared with the control, return bloom was significantly increased by CyLex alone, all ATS plus CyLex treatments and by the 1.2% and 1.4% triple ATS applications (Table 7.5).

Table 7.5: *The effect of ammonium thiosulphate (ATS) and CyLex on crop load and return bloom of Oregon spur 'Delicious' apples (Trial 2). TCSA, trunk cross-sectional area; wAFB, weeks after full bloom; ATS x 1, applied at 20% bloom; x2, double application at 20 & 80% bloom; x3, triple application at 20 & 80% bloom & 3 dAFB. CyLex applied 3 wAFB at 150 ppm. Ethephon applied at 80 ppm at full bloom.*

	No. fruit per 100 blossom clusters	No. fruit per cm^2 TCSA	Return bloom (no. buds per cm^2 TCSA)
Control	132	16.38	11.4
Hand-thin 4 wAFB	26	3.08	17.1
Ethephon	72	8.58	16.7
CyLex	51	6.84	19.6
Ethephon + CyLex	51	6.78	15.8
0.8% ATS x1	102	12.60	7.9
1.0% ATS x1	107	11.58	11.8
1.2% ATS x1	91	11.41	11.4
1.4% ATS x1	66	7.84	11.8
0.8% ATS x2	72	9.65	13.3
1.0% ATS x2	42	5.61	12.3
1.2% ATS x2	56	7.42	17.2
1.4% ATS x2	32	4.05	16.2
0.8% ATS x3	40	4.48	14.0
1.0% ATS x3	34	4.93	14.0
1.2% ATS x3	24	3.27	18.2
1.4% ATS x3	11	1.38	19.6
0.8% ATS x2 + CyLex	33	4.49	21.2
1.0% ATS x2 + CyLex	27	3.58	22.4
1.2% ATS x2 + CyLex	19	2.45	23.4
1.4% ATS x2 + CyLex	21	2.61	19.0
LSD (P=0.05)	*27*	*2.13*	*6.3*
Commercial target levels	*40-60*	*2-4*	

Fruit weight and size were both increased significantly by most treatments with the exception of the three lower single applications of ATS (Table 7.6). CyLex increased fruit weight significantly over the corresponding ATS alone treatments in three out of the four comparisons.

Table 7.6: *The effect of ammonium thiosulphate (ATS) and CyLex on mean fruit weight and fruit size (% fruit ≥ 70 mm diameter) of Oregon spur 'Delicious' apples (Trial 2). wAFB, weeks after full bloom; ATS x 1, applied at 20% bloom; x2, double application at 20 & 80% bloom; x3, triple application at 20 & 80% bloom & 3 dAFB. CyLex applied 3 wAFB at 150 ppm. Ethephon applied at 80 ppm at FB.*

	Mean fruit weight (g)	% fruit ≥ 70 mm diameter
Control	100	8
Hand-thin 4 wAFB	193	95
Ethephon	139	53
CyLex	151	63
Ethephon + CyLex	150	63
0.8% ATS x1	107	14
1.0% ATS x1	112	20
1.2% ATS x1	122	29
1.4% ATS x1	131	41
0.8% ATS x2	124	30
1.0% ATS x2	163	69
1.2% ATS x2	157	71
1.4% ATS x2	207	86
0.8% ATS x3	178	84
1.0% ATS x3	176	73
1.2% ATS x3	199	94
1.4% ATS x3	214	94
0.8% ATS x2 + CyLex	196	95
1.0% ATS x2 + CyLex	211	93
1.2% ATS x2 + CyLex	231	96
1.4% ATS x2 + CyLex	219	95
LSD (P=0.05)	*26*	*16*
Commercial target levels	*150*	*80*

There were significant linear regressions between mean fruit weight and crop load ($R^2 = 0.88$) (Figure 7.1), and between fruit size and crop load ($R^2 = 0.92$) (Figure 7.2).

Fruit length diameter ratio (Table 7.7) was significantly decreased compared with the control by the ethephon treatments and by all ATS treatments with the exception of the 1.0% ATS at 20 and 80% bloom and 0.8% ATS + CyLex treatments.

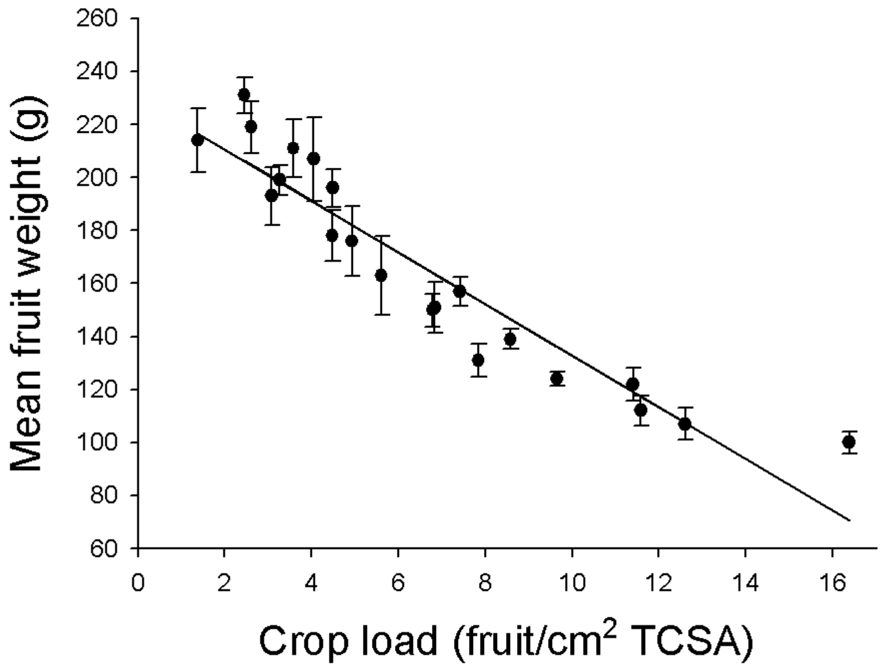


Figure 7.1: *The relationship between crop load and mean fruit weight of Oregon Spur 'Delicious' apple.*
The equation of the line is: $y = 230.3 - 9.75x$, $R^2 = 0.88$, $P < 0.001$

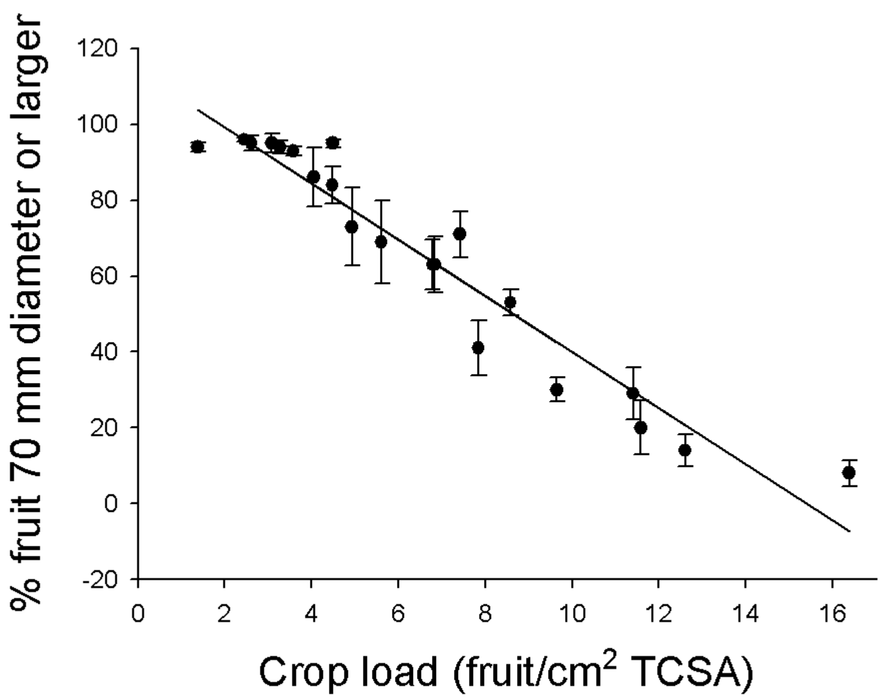


Figure 7.2: *The relationship between crop load and fruit size of Oregon Spur 'Delicious' apple.*
The equation of the line is: $y = 114.17 - 7.42x$, $R^2 = 0.92$, $P < 0.001$

Total soluble solids (Table 7.7) was increased significantly by all treatments compared with the control, except the 0.8% ATS at 20% bloom. There was a significant linear regression between soluble solids concentration and crop load (R^2 = 0.76) (Figure 7.3), and the greater the level of thinning achieved the higher the soluble solids concentration.

Fruit firmness was increased significantly by all treatments except ethephon (Table 7.7). CyLex increased firmness over and above that achieved by ATS.

Seed number (Table 7.7) was not affected by the ethephon treatments or the lower concentrations of ATS at 20% bloom but was significantly decreased by other treatments.

***Table 7.7**: The effect of ammonium thiosulphate (ATS) and CyLex on fruit shape (length/diameter ratio), sugar content, flesh firmness and seed number of Oregon spur 'Delicious' apples (Trial 2). wAFB, weeks after full bloom; ATS x 1, applied at 20% bloom; x2, double application at 20 & 80% bloom; x3, triple application at 20 & 80% bloom & 3 dAFB. CyLex applied 3 wAFB at 150 ppm. Ethephon applied at 80 ppm at full bloom.*

	Fruit length/diameter ratio	Total soluble solids (ºBrix)	Fruit flesh firmness (kg)	Average no. seeds per fruit
Control	0.998	12.12	11.44	6.7
Hand-thin 4 wAFB	0.996	13.05	12.38	5.1
Ethephon	0.938	12.50	11.67	6.2
CyLex	0.989	12.32	12.65	4.9
Ethephon + CyLex	0.927	12.77	11.54	6.3
0.8% ATS x1	0.963	12.20	11.80	6.4
1.0% ATS x1	0.965	12.40	11.76	6.4
1.2% ATS x1	0.977	12.67	11.87	5.8
1.4% ATS x1	0.976	12.77	11.94	5.7
0.8% ATS x2	0.973	12.35	11.96	6.4
1.0% ATS x2	0.988	13.20	12.10	5.0
1.2% ATS x2	0.969	12.92	11.81	5.1
1.4% ATS x2	0.978	13.20	12.03	5.0
0.8% ATS x3	0.975	12.97	12.18	5.0
1.0% ATS x3	0.982	13.27	11.73	5.4
1.2% ATS x3	0.961	13.85	12.07	4.7
1.4% ATS x3	0.981	13.80	12.55	5.0
0.8% ATS x2 + CyLex	0.982	13.27	12.71	4.2
1.0% ATS x2 + CyLex	0.963	13.22	13.11	4.4
1.2% ATS x2 + CyLex	0.970	13.50	12.96	4.6
1.4% ATS x2 + CyLex	0.977	13.60	12.84	5.3
LSD (P=0.05)	*0.016*	*0.12*	*0.28*	*0.8*

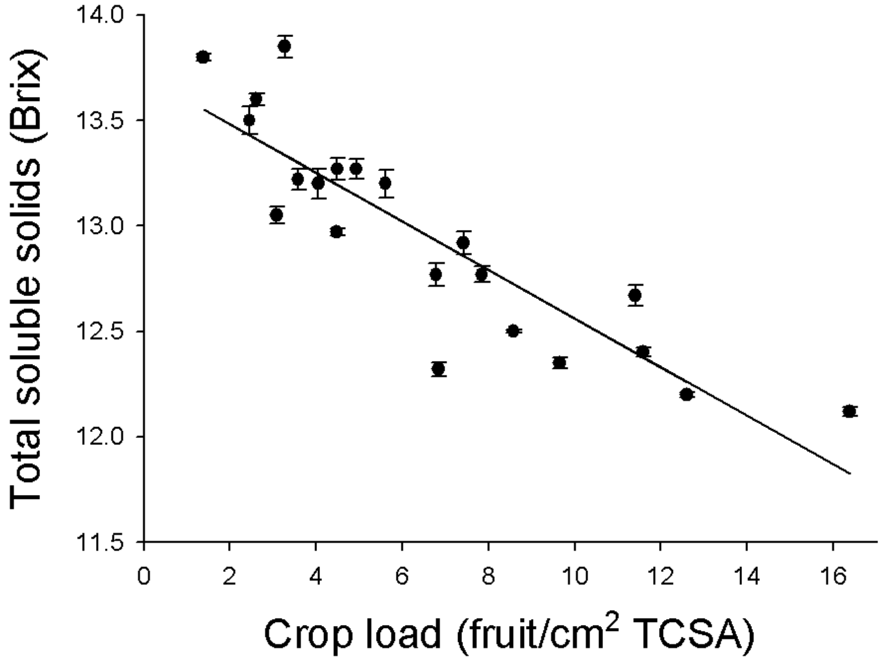


***Figure 7.3**: The relationship between crop load and fruit sugar content of Oregon Spur 'Delicious' apple.*
The equation of the line is: y = 13.71 – 0.115x, $R^2 = 0.76$, $P < 0.001$

Following three months in cold storage (Table 7.8), soluble solids content displayed similar patterns to those observed at harvest. Flesh firmness, although lower than at harvest, was highest in the hand-thin and CyLex treatments, the 1.4% double ATS, and the 1.2 and 1.4% triple ATS treatments.

***Table 7.8**: The effect of ammonium thiosulphate (ATS) and CyLex on fruit sugar content and flesh firmness of Oregon spur 'Delicious' apples following 3 months cold storage (Trial 2). WAFB, weeks after full bloom; ATS x 1, applied at 20% bloom; x2, double application at 20 & 80% bloom; x3, triple application at 20 & 80% bloom & 3 dAFB. CyLex applied 3 wAFB at 150 ppm. Ethephon applied at 80 ppm at full bloom.*

	Total soluble solids (Brix°)	Fruit flesh firmness (kg)
Control	11.73	6.63
Hand-thin 4 wAFB	13.30	7.31
ethephon	12.35	6.82
CyLex	12.55	7.17
ethephon + CyLex	12.50	6.87
0.8% ATS x1	11.78	6.68
1.0% ATS x1	11.98	6.72
1.2% ATS x1	14.20	6.65
1.4% ATS x1	12.63	7.01
0.8% ATS x2	11.95	6.77
1.0% ATS x2	12.99	6.92
1.2% ATS x2	13.10	6.81
1.4% ATS x2	13.25	7.21
0.8% ATS x3	12.95	6.94
1.0% ATS x3	13.28	7.00
1.2% ATS x3	13.65	7.23
1.4% ATS x3	14.35	7.30
0.8% ATS x2 + CyLex	13.50	7.65
1.0% ATS x2 + CyLex	13.93	7.77
1.2% ATS x2 + CyLex	13.53	7.65
1.4% ATS x2 + CyLex	14.05	7.47
LSD (P=0.05)	*0.21*	*0.19*

Trial 3 - Hi-Early 'Delicious'

Crop load was significantly reduced by the hand-thin, 1.0% ATS and the three CyLex treatments (Table 7.9), with the CyLex treatments reducing crop load significantly more than ATS alone.

Mean fruit weight was increased significantly above that in the control treatment by hand-thin and CyLex treatments. There was a significant linear regression between fruit weight and crop load (R^2 = 0.84) (Figure 7.4), with fruit weight decreasing by 9.8 g for each unit of crop load. Results for fruit size were similar to those for fruit weight (Table 7.9, Figure 7.5). There was no effect on return bloom (results not presented).

***Table 7.9**: The effect of ammonium thiosulphate (ATS) and CyLex on crop load, mean fruit weight and size (% fruit ≥ 70 mm diameter) of Hi-Early 'Delicious' apples (Trial 3). TCSA, trunk cross-sectional area; wAFB, weeks after full bloom; ATS applied as a double application at 20 & 80% bloom; CyLex applied 3 wAFB at 150 ppm.*

	No. fruit per 100 blossom clusters	No. fruit per cm^2 TCSA	Mean fruit weight (g)	% fruit ≥ 70 mm diameter
Control	85	6.21	127	36
Hand-thin 4 wAFB	54	4.51	157	73
0.8% ATS	79	5.13	132	45
1.0% ATS	59	3.85	142	55
1.2% ATS	66	4.85	141	52
0.8% ATS + CyLex	28	1.52	174	79
1.0% ATS + CyLex	22	1.61	178	87
1.2% ATS + CyLex	17	1.31	167	78
LSD (P=0.05)	*24*	*1.60*	*22*	*20*
Commercial target levels	*40-60*	*2-4*	*150*	*70*

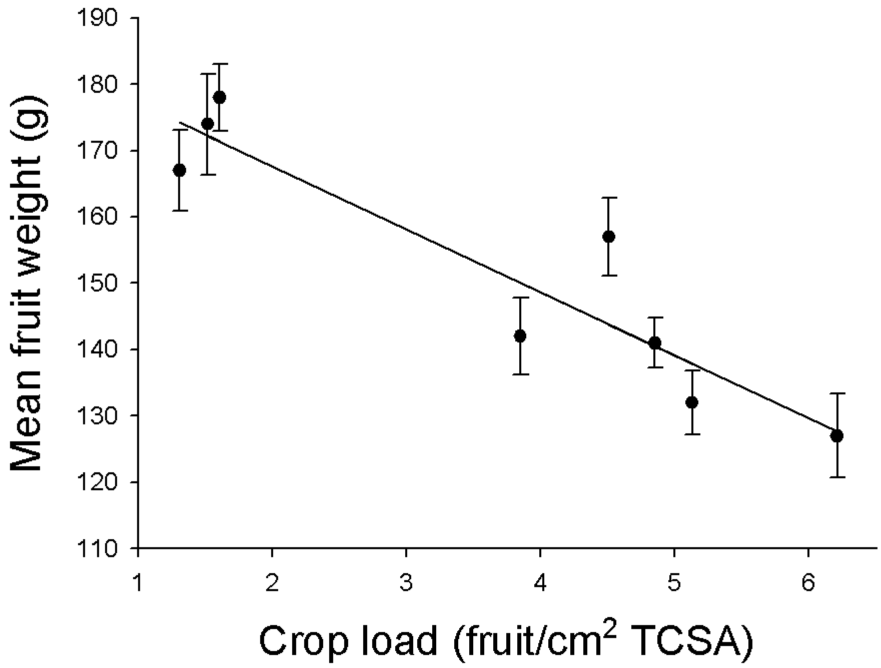


***Figure 7.4**: The relationship between crop load and mean fruit weight of Hi-Early 'Delicious' apple.*
The equation of the line is: y = 186.78 – 9.83x, R^2 = 0.84, P <0.001

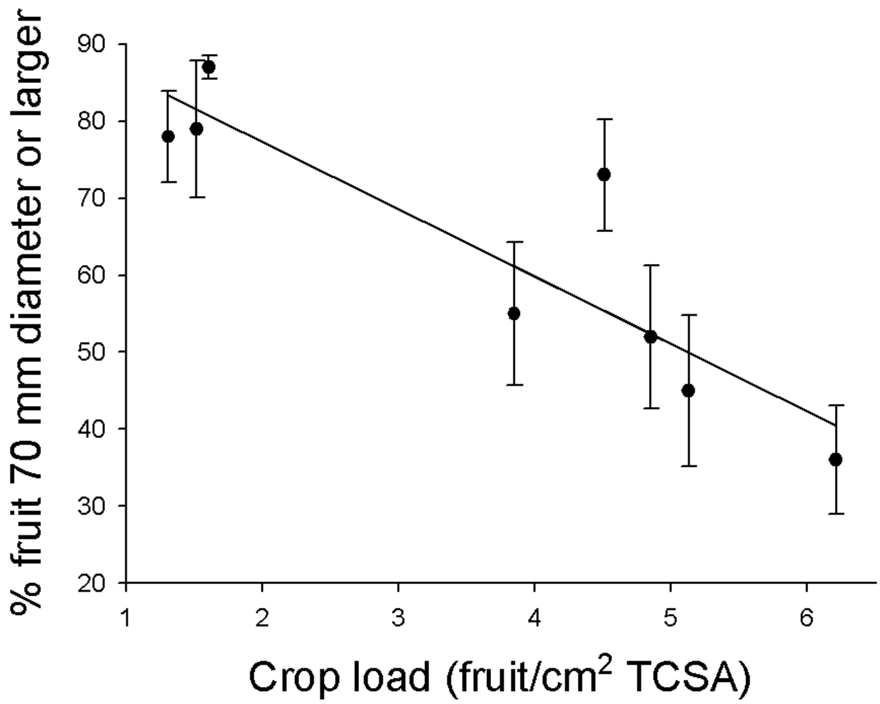


***Figure 7.5**: The relationship between crop load and fruit size of Hi-Early 'Delicious' apple. The equation of the line is:* y = 94.86 – 8.76x, R^2 = 0.77, P = 0.003

Fruit length/diameter ratio (Table 7.10) was significantly decreased by addition of CyLex. Soluble solids were significantly increased by all treatments, with CyLex increasing soluble solids over the ATS alone and hand-thin treatments. There was a significant positive linear regression between fruit length/diameter ratio and crop load (R^2 = 0.76) (Figure 7.6).

Fruit TSS was significantly increased by all treatments compared with the control (Table 7.10). Addition of CyLex increased TSS significantly compared with ATS alone. There were significant negative linear regressions between TSS and crop load (R^2 = 0.81) (Figure 7.7), and between TSS and mean fruit weight (R^2 = 0.66) (Figure 7.8).

All treatments significantly increased fruit firmness compared with the control (Table 7.10), except for the 0.8 and 1.2% ATS treatments. CyLex increased firmness significantly compared with that achieved by ATS or hand-thin treatments. There was a significant negative linear regression between fruit firmness and crop load (R^2

= 0.76) (Figure 7.9) and a positive linear regression between fruit firmness and mean fruit weight (R^2 = 0.85) (Figure 7.10). All treatments, except for 1.2% ATS plus CyLex, resulted in a significant reduction in seed numbers (Table 7.10).

***Table 7.10**: The effect of ammonium thiosulphate (ATS) and CyLex on fruit shape (length/diameter ratio), sugar content, flesh firmness and seed number of Hi-Early 'Delicious' apples (Trial 3). wAFB, weeks after full bloom. ATS applied at 20 & 80% bloom; CyLex applied 3 wAFB at 150 ppm.*

	Fruit length/diameter ratio	Total soluble solids (ºBrix)	Fruit flesh firmness (kg)	Average no. seeds per fruit
Control	0.935	11.58	12.29	6.5
Hand-thin 4 wAFB	0.929	12.10	13.20	5.8
0.8% ATS	0.937	12.16	11.90	5.9
1.0% ATS	0.928	12.00	12.65	5.5
1.2% ATS	0.937	12.26	12.37	5.7
0.8% ATS + CyLex	0.908	13.30	13.51	5.7
1.0% ATS + CyLex	0.918	12.67	13.61	5.5
1.2% ATS + CyLex	0.921	13.06	13.86	6.3
LSD (P=0.05)	*0.012*	*0.08*	*0.27*	*0.6*

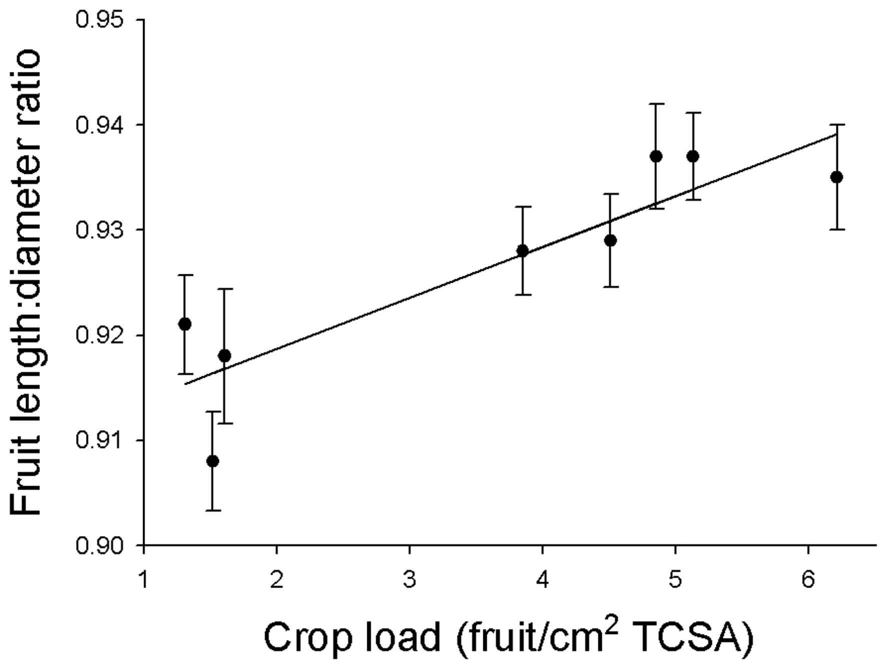


***Figure 7.6**: The relationship between crop load and fruit shape (length/diameter ratio) of Hi-Early 'Delicious' apple.*
The equation of the line is: y = 0.909 + 0.005x, R^2 = 0.76, P = 0.003

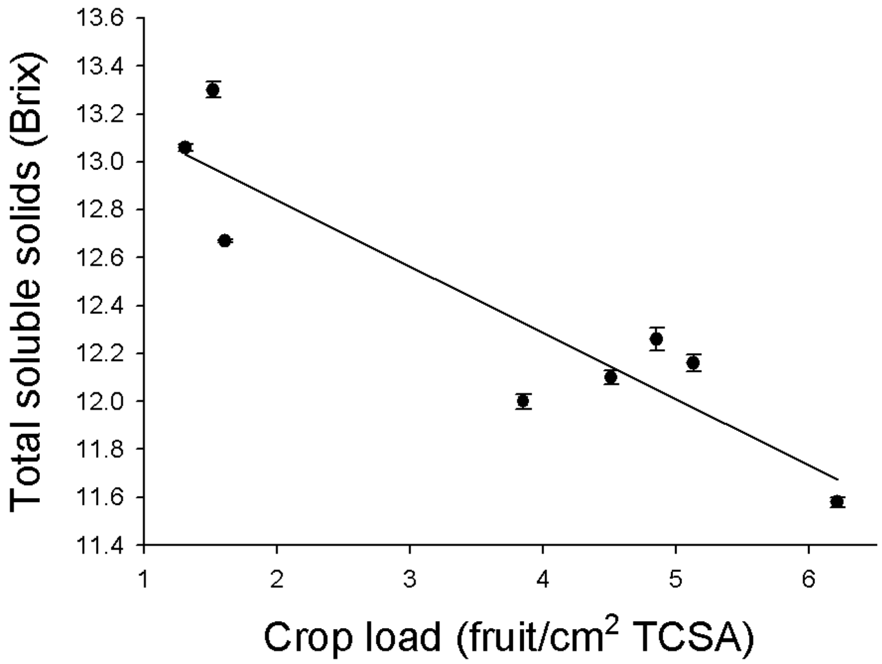


***Figure 7.7**: The relationship between crop load and fruit sugar content of Hi-Early 'Delicious' apple.*
The equation of the line is: y = 13.39 – 0.278x, R^2 = 0.81, P = 0.001

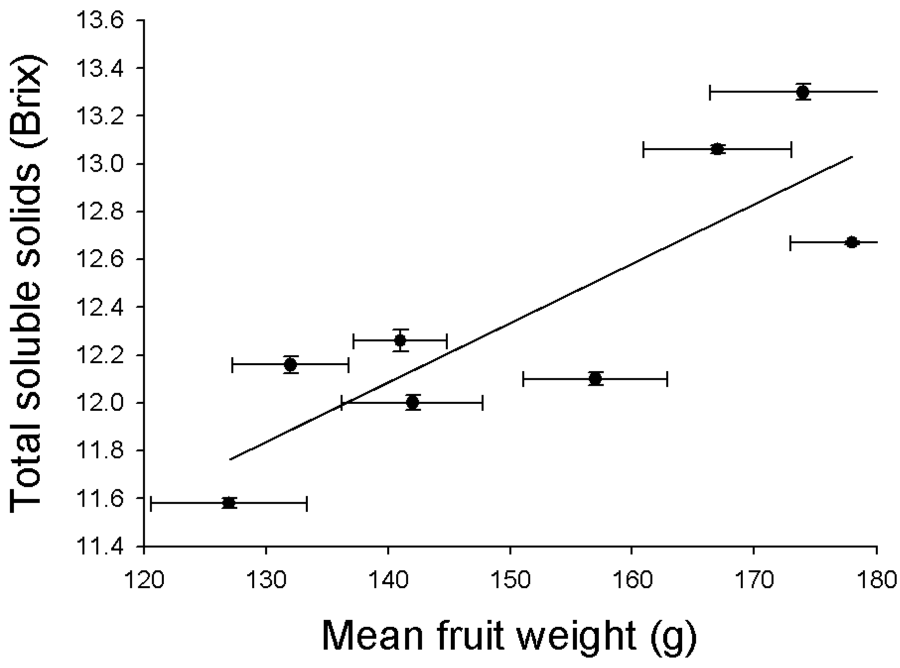


***Figure 7.8**: The relationship between fruit weight and sugar content of Hi-Early 'Delicious' apple.*
The equation of the line is: y = 8.60 + 0.025x, R^2 = 0.66, P = 0.009

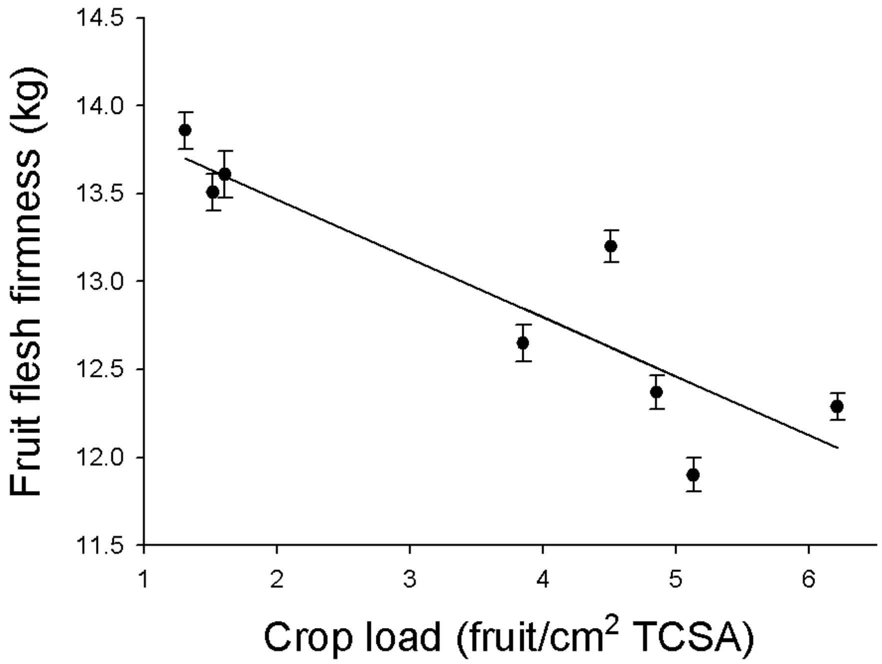


Figure 7.9: *The relationship between crop load and fruit flesh firmness of Hi-Early 'Delicious' apple.*
The equation of the line is: y = 14.14 – 0.337x, $R^2 = 0.76$, P = 0.003

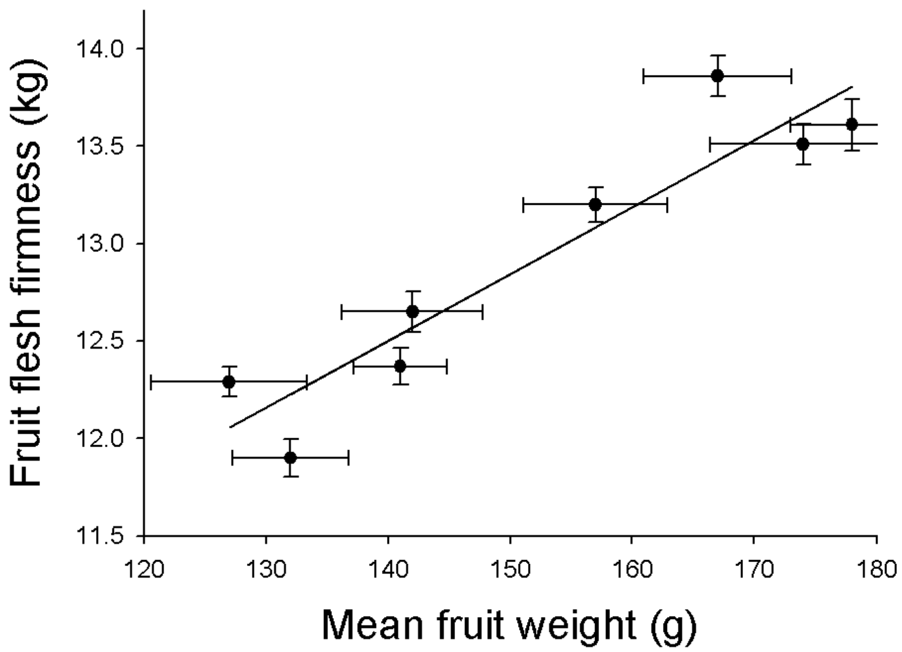


Figure 7.10: *The relationship between fruit weight and flesh firmness of Hi-Early 'Delicious' apple.*
The equation of the line is: y = 7.69 + 0.034x, $R^2 = 0.85$, P <0.001

Trial 4 - Hi-Early 'Delicious'

Both crop load variables were significantly reduced by all treatments compared with the control (Table 7.11). Although there was no difference between the two concentrations, increasing the number of applications of ATS increased the thinning effect. Adding CyLex to the thinning program had a further thinning effect. Commercial target levels were achieved in the hand-thin, and double and triple 1.0% ATS treatments. The triple ATS treatments and both CyLex treatments reduced both crop load variables to below target levels.

Mean fruit weight and size (Table 7.11) were increased significantly by all treatments except for the single ATS applications. Treatments that achieved higher thinning levels had heavier fruit and a higher percentage of fruit ≥ 70 mm diameter, with significant linear regressions between mean fruit weight and crop load (R^2 = 0.91) (Figure 7.11) and between fruit size and crop load (R^2 = 0.90) (Figure 7.12).

Table 7.11*: The effect of ammonium thiosulphate (ATS) and CyLex on crop load, mean fruit weight and size (% fruit ≥ 70 mm diameter) of Hi-Early 'Delicious' apple (Trial 4). wAFB, weeks after full bloom; ATS x1, single application at 20% bloom; x2, double application at 20 & 80% bloom; x3, triple application at 20 & 80% bloom & 3 dAFB. CyLex applied 3 wAFB at 150 ppm.*

	No. fruit per 100 blossom clusters	No. fruit per cm^2 TCSA	Mean fruit weight (g)	% fruit ≥ 70 mm diameter
Control	132	7.92	114	25
Hand-thin 4 wAFB	60	3.74	149	62
1.0% ATS x1	84	5.67	128	37
1.2% ATS x1	99	5.87	127	36
1.0% ATS x2	54	3.97	177	74
1.2% ATS x2	70	4.10	166	67
1.0% ATS x3	42	2.61	197	88
1.2% ATS x3	28	1.74	199	90
1.0% ATS x2 + CyLex	13	0.85	208	90
1.2% ATS x2 + CyLex	17	0.74	230	89
LSD (p=0.05)	*23*	*1.53*	*21*	*15*
Commercial target levels	*40-60*	*2-4*	*150*	*70*

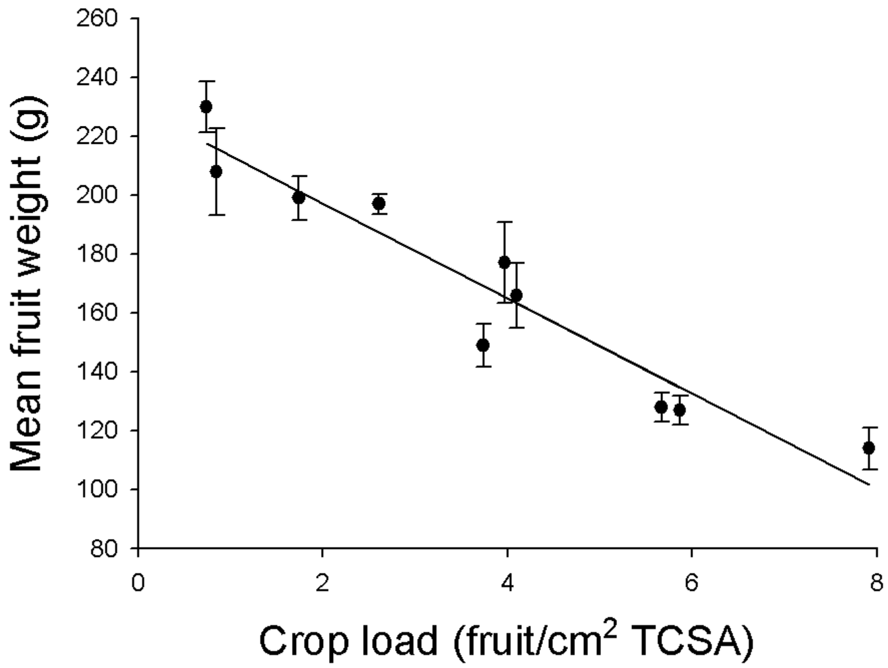


Figure 7.11*: The relationship between crop load and mean fruit weight of Hi-Early 'Delicious' apple.*
The equation of the line is: y = 229.67 – 16.17x, R^2 = 0.91, P <0.001

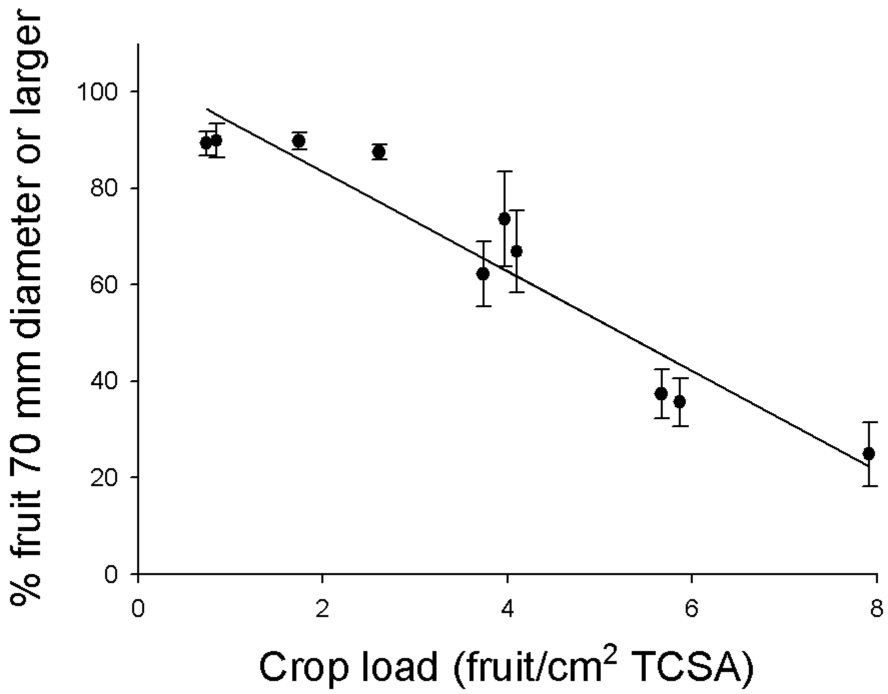


Figure 7.12*: The relationship between crop load and fruit size of Hi-Early 'Delicious' apple.*
The equation of the line is: y = 104.06 – 10.30x, R^2 = 0.90, P <0.001

Compared with the control, fruit L/D ratio was increased significantly by the single and triple 1.2% ATS treatments, a single ATS at 1.0% and both treatments with CyLex (Table 7.12). There was a significant decrease in TSS in both the single and double applications of 1.0% ATS. The double 1.2% ATS treatments increased TSS significantly, as did both triple applications. CyLex increased TSS over that recorded in the double applications.

Fruit firmness was significantly increased by the hand-thin, triple ATS and CyLex treatments compared with the control. Three applications of ATS increased firmness more than two. Addition of CyLex significantly increased firmness compared with the corresponding double applications. The hand-thin and 1.2% ATS + CyLex treatments both produced the firmest fruit compared with all other treatments.

Seed number was significantly reduced by the double and triple ATS treatments, while CyLex reduced seed number further.

***Table 7.12**: The effect of ammonium thiosulphate (ATS) and CyLex on fruit length/diameter ratio, sugar content, fruit firmness and seed number of Hi-Early 'Delicious' apples (Trial 4). wAFB, weeks after full bloom; ATS x1, single application at 20% bloom; x2, double application at 20 & 80% bloom; x3, triple application at 20 & 80% bloom & 3 dAFB. CyLex applied 3 wAFB at 150 ppm.*

	Fruit length/diameter ratio	Total soluble solids (°Brix)	Fruit flesh firmness (kg)	Average no. seeds per fruit
Control	0.930	14.85	8.06	3.9
Hand-thin 4 wAFB	0.927	14.82	8.74	3.5
1.0% ATS x1	0.943	14.70	7.99	3.8
1.2% ATS x1	0.945	14.93	7.92	3.9
1.0% ATS x2	0.935	14.69	8.04	3.3
1.2% ATS x2	0.924	15.32	8.17	2.9
1.0% ATS x3	0.938	15.10	8.36	3.0
1.2% ATS x3	0.948	15.52	8.45	3.3
1.0% ATS x2 + CyLex	0.980	15.50	8.33	2.4
1.2% ATS x2 + CyLex	0.971	15.45	8.64	2.0
LSD (p=0.05)	*0.010*	*0.13*	*0.19*	*0.6*

3. Potassium thiosulphate as a blossom thinner

Application rates for KTS in this study were selected on the assumption that KTS would have a similar thinning action to ATS. Based on the studies with ATS described earlier in this chapter, all KTS treatments were applied as two sprays, with the first at 20% bloom and the second at 80% bloom.

3.1. Materials and methods

Two separate trials were established on mature regular bearing trees in the Huon Valley. Trial 1 was established on 10-year-old Oregon Spur ‘Delicious’ trees on MM106 rootstock at Grove. Trees were approximately 2 m in height, trained to a central axis system, with a spacing of 4 m between rows and 2 m within the row. Trial 2 was established on 7-year-old 'Royal Gala' trees on MM106 rootstock at Lucaston. Trees in Trial 2 were approximately 2.5 m in height, trained to a central axis system, with a spacing of 5 m between rows and 2 m within the row.

Trial design

Trial 1: Twenty four trees were blocked into four blossom density groups and six treatments allocated at random to single tree plots within each block, giving four replicates per treatment.

Trial 2: Twenty trees were blocked into five blossom density groups and four treatments allocated at random to single tree plots within each block, giving five replicates per treatment.

Treatments

Trial 1: Two applications (20 & 80% bloom) of KTS (21% K, 17% S; formulated as a liquid fertiliser) were applied at either 0.5, 1.0 or 1.5% (v/v) (Bound and Jones 2004). These three treatments were compared with an untreated control, a treatment hand-thinned 4 wAFB, and 80 ppm ethephon applied at FB, which is the industry standard for ‘Delicious’ in Tasmania (Jones *et al*. 1998).

Trial 2: KTS was applied at 30 & 80% bloom at rates of 0.5, 1.0 or 1.5% (v/v). The initial application was scheduled for 20% bloom, however high winds made spray application impossible and this application was delayed to 30% bloom. An untreated control was also included.

In both trials, all sprays were applied with an hydraulic hand lance at a spray volume of 2,500 L/ha. The wetter Tween 20 was included at the rate of 1.25 ml/L with all spray applications.

Assessments

Blossom density was assessed in early October as described in Chapter 3.

Trees were assessed visually for phytotoxic damage three weeks after spray application. Damage was rated as described by Bound and Jones (1997) using an arbitrary scale from 0 (no damage) to 10 (severe damage and death of the apical buds).

At normal commercial harvest time in March, fruit from each tree were counted and weighed, and number of fruit/100 blossom clusters, number of fruit/cm^2 TCSA and mean fruit weight calculated.

Fruit were graded as described in Chapter 3, and number of fruit ≥ 70 mm diameter determined for both cultivars. 'Delicious' fruit samples were also assessed for L/D ratios, TSS, firmness and seed number as described in Chapter 3.

Return bloom was determined as described in Chapter 3.

Data analysis

In each trial, data were analysed by analysis of variance as described in Chapter 3.

3.2 Results

In both 'Delicious' and 'Royal Gala', no leaf damage was observed on leaves on the control (Table 7.13). There was no damage in the hand-thin and ethephon treatments in the 'Delicious' trial.

Table 7.13*: Degree of leaf damage following application of the desiccant potassium thiosulphate (KTS) applied as a blossom thinner on 'Delicious' and 'Royal Gala' trees. Damage rated using a scale from 0 (no damage) to 10 (severe damage and death of the apical buds). FB, full bloom; wAFB, weeks after full bloom.*

	'Delicious'	'Royal Gala'
Control	0	0
Hand-thin 4 wAFB	0	-
80 ppm ethephon at FB	0	-
0.5% KTS	0	0
1.0% KTS	1	1
1.5% KTS	3	2

While flower petals were visibly damaged, there was no leaf damage at the lower application rates of 0.5% ATS (Figure 7.13). There was some marginal necrosis of the leaves in trees treated with either 1.0% or 1.5% KTS in both 'Delicious' and 'Royal Gala' trials (Figure 7.14).

Trial 1 - 'Delicious'

Number of fruit/100 blossom clusters was significantly reduced by all treatments compared with the control (Table 7.14). Both the hand-thin and 1.5% KTS treatments over-thinned, reducing crop load to below commercial target levels, whilst the 0.5 and 1.0% KTS treatments thinned to within the target range. Although ethephon significantly reduced crop load, it did not achieve target levels. The number of fruit/cm^2 TCSA was significantly reduced by all treatments. While the ethephon treatment halved this crop load variable, it did not achieve as much thinning as the hand-thin or any of the KTS treatments. The hand-thin, 0.5% and 1.0% KTS treatments all achieved commercial target loads for this variable, while 1.5% KTS over-thinned.

Figure 7.13: *'Delicious' flowers and leaves 24 hours after application of 0.5% potassium thiosulphate*

Figure 7.14: *Marginal leaf burning and necrosis evident in 'Delicious' leaves 10 days after application of 1.5% potassium thiosulphate.*

All treatments, including the control achieved good return bloom (Table 7.14), with no significant differences between treatments.

***Table 7.14**: The effect of the desiccant potassium thiosulphate (KTS) applied as a blossom thinner on crop load and return bloom of 'Delicious' apples (Trial 1). FB, full bloom; wAFB, weeks after full bloom.*

	No. fruit per 100 blossom clusters	No. fruit per cm^2 TCSA	Return bloom (no. buds per cm^2 TCSA)
Control	132	16.38	11.4
Hand-thin 4 wAFB	26	3.08	17.1
80 ppm ethephon at FB	72	8.58	16.7
0.5% KTS at 20 & 80% bloom	51	2.82	15.8
1.0% KTS at 20 & 80% bloom	51	2.85	15.6
1.5% KTS at 20 & 80% bloom	26	1.40	12.4
LSD (P=0.05)	*32*	*1.68*	*ns*
Commercial target levels	*40-60*	*2-4*	

Mean fruit weight was increased significantly by all treatments compared with the control (Table 7.15). The hand-thin and all KTS treatments achieved significantly higher fruit weights than the ethephon treatment. Commercial target levels for fruit weight were achieved by the hand-thin and all KTS treatments.

Fruit size, represented as percent fruit ≥ 70 mm diameter, followed a similar pattern to fruit weight. The only treatments that failed to achieve commercial target levels were the control and ethephon treatments.

Fruit L/D ratio was significantly reduced by all chemical spray treatments (Table 7.16), with ethephon and 0.5% KTS resulting in the greatest reduction. The lower rate of KTS reduced L/D ratio significantly more than the highest rate. Ethephon had no effect on seed number compared with the control, while all other treatments significantly reduced seed number, including the hand-thin treatment.

Fruit TSS was significantly increased by all treatments compared with the control (Table 7.17). TSS was significantly higher in the hand-thin treatment than the ethephon treatment, while the KTS treatments resulted in an even greater increase. Fruit firmness (Table 7.17) was increased significantly in the hand-thin treatment compared with the control, but decreased by the 1.5% rate of KTS. Neither the 0.5%, 1.0% KTS or ethephon treatments had any significant effect on fruit firmness.

Table 7.15: *The effect of the desiccant potassium thiosulphate (KTS) applied as a blossom thinner on mean fruit weight and size (% fruit ≥ 70 mm diameter) of 'Delicious' apples (Trial 1). FB, full bloom; wAFB, weeks after full bloom.*

	Mean fruit weight (g)	% fruit ≥ 70 mm diameter
Control	99	8
Hand-thin 4 wAFB	193	95
80 ppm ethephon at FB	139	53
0.5% KTS at 20 & 80% bloom	180	84
1.0% KTS at 20 & 80% bloom	179	84
1.5% KTS at 20 & 80% bloom	225	91
LSD (P=0.05)	*25*	*9*
Commercial target levels	*150*	*75*

Table 7.16: *The effect of the desiccant potassium thiosulphate (KTS) applied as a blossom thinner on fruit shape (length/diameter ratio) and seed number of 'Delicious' apples (Trial 1). FB, full bloom; wAFB, weeks after full bloom.*

	Fruit length/diameter ratio	Average no. seeds per fruit
Control	0.998	6.7
Hand-thin 4 wAFB	0.996	5.1
80 ppm ethephon at FB	0.938	6.2
0.5% KTS at 20 & 80% bloom	0.943	5.7
1.0% KTS at 20 & 80% bloom	0.958	5.4
1.5% KTS at 20 & 80% bloom	0.964	5.7
LSD (P=0.05)	*0.016*	*0.8*

Table 7.17: *The effect of the desiccant potassium thiosulphate (KTS) applied as a blossom thinner on fruit sugar content and flesh firmness of 'Delicious' apples (Trial 1). FB, full bloom; wAFB, weeks after full bloom.*

	Total soluble solids (Brix°)	Fruit flesh firmness (kg)
Control	12.12	11.44
Hand-thin 4 wAFB	13.05	12.40
80 ppm ethephon at FB	12.50	11.67
0.5% KTS at 20 & 80% bloom	13.62	11.27
1.0% KTS at 20 & 80% bloom	13.85	11.32
1.5% KTS at 20 & 80% bloom	14.40	10.82
LSD (P=0.05)	*0.094*	*0.27*

Trial 2 – 'Royal Gala'

Both number of fruit/100 blossom clusters and number of fruit/cm^2 TCSA were significantly reduced by KTS (Table 7.18). The highest rate of KTS had a significantly greater thinning effect on number of fruit/cm^2 TCSA than the lower application rates.

Mean fruit weight (Table 7.19) was significantly increased by both the 1.0 and 1.5% KTS treatments. All KTS treatments significantly increased the percentage of fruit ≥ 70 mm diameter, with no significant difference between the different concentrations.

***Table 7.18**: The effect of the desiccant potassium thiosulphate (KTS) applied as a blossom thinner on crop load (number of fruit/100 blossom clusters and number of fruit/cm^2 TCSA) of 'Royal Gala' (Trial 2). TCSA, trunk cross-sectional area.*

	No. fruit per 100 blossom clusters	No. fruit per cm^2 TCSA
Control	189	11.58
0.5% KTS @ 30 & 80% bloom	108	6.67
1.0% KTS @ 30 & 80% bloom	97	6.95
1.5% KTS @ 30 & 80% bloom	72	4.29
LSD (P=0.05)	*49*	*1.72*

***Table 7.19**: The effect of the desiccant potassium thiosulphate (KTS) applied as a blossom thinner on mean fruit weight and size (% fruit ≥ 70 mm diameter) of 'Royal Gala' (Trial 2).*

	Mean fruit weight (g)	% fruit ≥ 70mm diameter
Control	124	25
0.5% KTS @ 30 & 80% bloom	135	46
1.0% KTS @ 30 & 80% bloom	139	55
1.5% KTS @ 30 & 80% bloom	146	61
LSD (P=0.05)	*14*	*21*

4. Discussion

This work has demonstrated that both ammonium and potassium thiosulphate applied to apple trees as thinning agents during the flowering period can improve fruit quality. In addition, combining ATS in a program with the post-bloom thinner CyLex has no adverse effects on fruit size or quality. ATS has been shown to be an effective thinner of 'Delicious' apple, confirming the preliminary results of Bound and Jones (2004). Multiple applications of ATS achieve better thinning than a single application. The successful thinning achieved in two apple cultivars with different flowering habits demonstrates that KTS also has potential as a blossom thinner.

4.1: Ammonium thiosulphate

When using desiccating chemicals to remove excess flowers from the tree, concentration needs to be sufficiently high to inactivate the style/stigma without damaging the receptacle, which forms the fruit, or causing excessive damage to leaves and buds (Bound 2001a). With ATS, Bound and Jones (2004) showed that concentrations below 0.3% were ineffective, while rates as high as 3.0% and above caused severe leaf damage. The 0.5-1.5% levels used in this study achieved sufficient damage to the reproductive organs to reduce fruit set without causing unacceptable leaf or fruit damage.

As noted by Bound and Jones (1997) and Bound (2001a), time of application is a critical issue when applying desiccating chemicals to reduce crop load. The lack of thinning achieved in trial 1 with a single application of ATS at 80% bloom contrasts with the results achieved at 20% bloom in trial 2. Jones *et al*. (1998) report that only 7-10% of flowers are required to set to ensure a good crop load, hence to ensure that fruit set is reduced to an adequate level, it is vital to apply desiccants relatively early in the flowering period. However, the length of the flowering period in each cultivar and added seasonal effects should also be taken into account.

Multiple applications of ATS at low concentration reduced fruit set as effectively as a single application at a higher rate. Two applications of 0.8% achieved the same thinning levels as one application of 1.4%, and three applications at the lower rate achieved the same results as two applications at the higher rate. A similar effect was reported by Bound (2001a) with the desiccant endothal (dipotassium 7,oxabicyclo (2,2,1) heptane-2-3 dicarboxylate). It appears that the relatively short period from opening, during which individual flowers are sensitive, may offer a way of using relatively low concentrations of ATS to adjust thinning severity over the flowering period. This strategy also provides a method to reduce the risk of over-thinning as well as a reduction in the total amount of chemical applied to the trees. In the present trials with 'Delicious', which has a relatively short flowering period, three applications tended to result in over-thinning. In cultivars with long flowering periods, or in seasons where weather conditions result in protracted flowering, more than two applications could have greater benefit, allowing more flowers to be targeted.

The addition of CyLex after two applications of ATS improved the thinning effect and, although this resulted in over-thinning in trials 3 and 4, it illustrates that CyLex can be used as a post-bloom thinner after ATS has been used during bloom.

In this study, those treatments resulting in the greatest reduction in crop load exhibited the highest fruit weights, with a linear correlation between fruit weight and crop load. As increased thinning normally results in larger fruit size (Jones *et al.* 1998), this trend was expected. However, there is evidence to suggest that some thinners, including ethephon and NAA, depress fruit growth, inhibiting achievement of optimum fruit weight potential (Link 1967; Way 1971; Wertheim 1974; Flore 1978; Knight 1980; Jones *et al.* 1983). Link (2000) reported that fruit size did not correspond to the crop load when ATS concentration and spray volume were high, suggesting that ATS may retard fruit growth. However, the results of this work show no negative impact of ATS on fruit weight at concentrations of 0.5-1.5%.

As discussed in chapter 6, fruit shape is an important marketing quality in 'Delicious', and anything that flattens the fruit is likely to be an issue for growers (Williams and Stahly 1969; Veinbrandts 1979). There is limited information available on the effects of blossom desiccants on fruit shape. Bound and Jones (1997) and Bound (2001a) have described the fruit flattening effect of the desiccant endothal. Although Bound and Jones (2004) showed that ATS increased fruit length in 'Delicious' the effect of ATS in these trials was variable. Fruit L/D ratio was reduced in the spur type 'Delicious', while in the non-spur bearing Hi-Early selection there was no effect in two of the trials but L/D ratio was increased by triple ATS applications in trial 4. The positive correlation between fruit L/D ratio and crop load in one of the Hi-Early 'Delicious' trials is difficult to explain but is more likely to be attributable to other factors such as climatic conditions rather than a direct effect of ATS. The effect of CyLex on fruit shape was also inconsistent but the fruit flattening effect of ethephon was consistent with the findings of Bound *et al*. (1993a).

Fruit sugar content and firmness were both increased by ATS, and in general, the greater the number of applications, the higher the firmness and sugar content of the fruit. Combined with the findings of Bound and Jones (1997) and Bound (2001a), who reported that thinning with endothal also produced firmer fruit with high sugar content, this suggests that thinning with blossom desiccants may have a positive effect on these measures of fruit quality. The additional increase in both sugar content and firmness with CyLex again parallels the findings of Bound (2001a). At first glance the results of this work suggest that the reduced sugar content at high crop loads may be due to delayed fruit maturity in trees carrying heavier crops. However fruit from trees with higher crop loads were also softer. While this disagrees with the delayed maturity argument, it can be explained by reduced cell numbers in these fruit. Robinson and Watkins (2004) observed a similar effect in 'Honeycrisp' apple. As the relationship between larger/sweeter fruit and firmness is normally negative, the potential to produce firm sweet fruit is a factor which should be considered when choosing chemicals for a thinning program, particularly if fruit is destined for long term storage.

Thinning agents applied at or after flowering can have a dramatic effect on seed abortion (Williams and Edgerton 1981; Williams 1986). Bramlage *et al*. (1990) has reported that low seed numbers can have an adverse effect on fruit quality and Williams (1977) reported negative effects on fruit size. However, the slight reduction in seed numbers in this work was similar to results of earlier work by Bound and Jones (2004), and is unlikely to have a direct impact on fruit quality. Although CyLex reduced seed number to a greater extent than ATS, the positive effect of CyLex on both fruit soluble solids and firmness as well as size appears to have counteracted the negative effects of reduced seed numbers. This effect is similar to that reported by Bound (2001a), where CyLex reduced seed numbers when applied in a program with the desiccant endothal, but increased fruit size, firmness and soluble solids content, over-riding any detrimental effects of reduced seed numbers.

The effect of ATS on fruit skin finish in this work was minimal, with only one treatment increasing fruit russet. Chemically induced russet can be a serious problem as fruit that is russeted is normally downgraded to second grade or juice. High rates of chemical are more likely to result in fruit russet than low rates, Bound and Jones (2004) reported that ATS applied at 4.0% caused fruit russet, but there was no damage at lower rates. The same effect has been reported with CyLex (Bound *et al*. 1991b).

4.2: Potassium thiosulphate

Under Australian conditions, ‘Delicious’ has a relatively short flowering period (1-2 weeks) whereas, depending on seasonal weather patterns, ‘Royal Gala’ flowers over a 4-6 week period. The reduction in crop load seen in ‘Royal Gala’ was not as great as in ‘Delicious’, even at the higher rate of application of KTS. This could be due to the slightly later application of the first KTS spray (30% bloom compared with 20% bloom in ‘Delicious’), allowing a higher percentage of flowers to set. The longer flowering period in ‘Royal Gala’ also meant that at any one time there was a lower proportion of flowers open in ‘Royal Gala’ compared with ‘Delicious’, and consequently fewer flowers open and susceptible to spray damage at each application. Hildebrand (1944) showed that application of blossom thinners must be within 24-36 hours after flower opening to effectively inhibit pollen tube growth and subsequent fruit set. McArtney *et al*. (2002) concluded that as many as four applications of bloom desiccant materials was required under protracted spring flowering in New Zealand. Thus, in cultivars with long flowering periods such as 'Royal Gala', better thinning may be achieved with three applications rather than two.

The importance of concentration of blossom desiccants in relation to phyto-toxicity was addressed by Bound and Jones (1997). The work reported here showed that KTS will thin effectively from concentrations as low as 0.5% and up to 1.5% without resulting in excessive leaf or fruit damage, allowing the advantages of thinning without any significant damage.

As seen in the ATS studies described earlier, fruit weight was related to crop load, with those treatments resulting in the greatest reduction in crop load exhibiting the highest fruit weights. However, in 'Gala', while the 1.5% rate of KTS achieved greater thinning than the 1% rate, there was no corresponding increase in fruit weight or size. This suggests that there is a direct negative effect on fruit growth at higher concentrations of KTS, supporting the postulation of Link (2000) that the desiccant ATS may retard fruit growth to the extent that fruit size does not relate to the crop load obtained when ATS concentration and spray volume are high.

While KTS had a fruit flattening effect on 'Delicious' in this work it was not as marked as the flattening effect of ethephon, described by Bound *et al*. (1993a). In this study the higher rate of KTS had less effect on fruit flattening than the lower rate. This effect was also seen in the work reported by Bound and Jones (2004) with single applications of ATS. Normally, the expectation would be for the higher chemical rate to have a more pronounced effect, as seen in the studies with ATS reported in this chapter.

Although seed number has been reported to affect fruit size (Williams 1977) and fruit quality (Bramlage *et al*. 1990), the reduction seen in this work by both hand-thinning and KTS application is relatively small in biological terms and is unlikely to have any major impact on fruit quality. Both endothal (Bound 2001a) and ATS (Bound and Jones 2004) have been shown to have a similar effect of reducing seed numbers. A possible explanation for the reduced seed numbers seen in the hand-thin treatment, is that the larger fruit left on the trees following hand-thinning would have been from earlier opening flowers, and weather conditions during this period were windy, reducing bee activity, leading to reduced pollination and thus lower seed numbers. The same argument could also be applied to the KTS treatments, as those fruit remaining are likely to have been from the earlier opening flowers. Alternatively, it may be due to a less competitive environment, with less seeds required for fruit to set and be retained on the tree as a result of reduced competition between flowers due to thinning.

The increase in soluble solids content with increasing concentration of KTS parallels the increase noted by Bound and Jones (1997) with endothal, and with ATS as reported earlier in this chapter. This may be related to the thinning effect as those treatments with the higher sugar content also achieved the greatest reduction in crop load. Link (2000) also reported that fruit thinning gives 2-3% more soluble solids. In addition, if the earliest opening flowers are preserved as suggested above, in long flowering cultivars such as ‘Royal Gala’ the period between fertilisation of the older and younger flowers is 4-6 weeks – this could affect fruit maturity and thus sugar levels.

With the reduction in crop load achieved by early thinning, there is an expectation that fruit would be firm as a result of higher cell numbers (Goffinet *et al*. 1995; Link 2000). However, those treatments that achieved target crop load levels had no effect on fruit firmness. In addition, the highest rate of KTS produced large fruit as a result of over-thinning, yet produced the softest fruit, indicating that KTS has a detrimental effect on fruit firmness, or that these fruit were more mature than fruit from trees with higher crop loads. This may be related to cell size and number, however further work is required to define this relationship. In discussing the impact of thinning on fruit firmness, Link (2000) stated that generally thinning increases fruit firmness, but in some instances a decrease is observed. If thinning is performed early in the season, before the completion of cell division within the fruit (Webster, 1997), the reduced competition for resources allows fruit to develop greater cell numbers, thus explaining the increased firmness with thinning. However, if thinning is performed later in the season and cell size, rather than cell number, is increased as a result of a greater share of resources for individual fruit, then fruit are likely to be less firm.

Chapter 8

The impact of foliar damage on fruit quality, crop load and return bloom

1. Introduction

Loss of leaf area can occur at any time during the growing season as a result of defoliation by pests, leaf damage caused either by pests or disease, or phytotoxic damage following pesticide application. In particular, desiccating chemicals applied during the flowering period as blossom thinners can cause necrosis of leaves, resulting in reduced leaf area. There is considerable concern amongst orchardists that the damage caused to foliage by the desiccants now being examined for use as thinning agents during the blossom period may affect fruit quality. Although damage is usually restricted to slight marginal necrosis of the leaves when these chemicals are applied at the recommended rates (see Chapter 7), many growers are still reticent to use desiccants. They have not seen any leaf damage with other chemicals registered as thinning agents in Australia, and are unsure of the effects of reduced leaf area, no matter how small, on fruit quality.

For optimal fruit set, growth and quality, the importance of healthy spur leaves early in the season has been described by Proctor and Palmer (1991). Furthermore, loss of leaf area after flowering has been reported to reduce return bloom and fruit set the following year (Davis *et al*. 2000).

Many researchers have discussed the issue of phytotoxicity when using desiccating chemicals. Irving *et al.* (1989) found that high rates of ATS caused severe scorching of flowers, leaves and meristems. Warner (1993) discussed leaf twisting and browning of tender leaves as a result of ATS applications. The chemical Armourthin® (Akzo Nobel) has been shown to cause leaf burn and shoot dieback (Southwick *et al.* 1996). Bound and Jones (1997) suggested that excessive foliar damage following application of desiccating chemicals during flowering is likely to affect fruit size. Although several studies relating to foliar feeding by pests throughout the season have shown that leaf damage impacts on fruit size (Zwick *et al.* 1976; Ames *et al.* 1984; Beers *et al.* 1987; Francesconi *et al.* 1996; Lakso *et al.* 1996), firmness (Zwick *et al.* 1976) and sugar content (Ames *et al.* 1984), there is scant information available on the impact of foliar damage during the blossom period on fruit quality characteristics.

The series of trials reported here examined the impact of leaf damage on crop load, fruit quality and return bloom by simulating leaf damage as caused by desiccants applied as thinning chemicals during the flowering period.

2. Materials and methods

Three trials were conducted at Grove in the Huon Valley over a three year period. Trial 1 was on nine-year-old Oregon Spur 'Delicious' trees on MM106 rootstocks, and the following year, trial 2 was on 14-year-old Oregon Spur 'Delicious' trees on seedling rootstocks. Five-year-old 'Royal Gala' trees on MM106 rootstocks were used for trial 3. Trees in each trial were approximately 2 m in height, trained to a central axis system and spaced at 4 m between and 2 m within rows with an east-west row orientation.

Trees were selected as described in Chapter 3. Five replicates per treatment were used in trial 1, six replicates in trial 2 and four replicates in trial 3.

2.1: Treatments

Treatments involved reduction of leaf area to varying degrees to simulate leaf damage. In trials where a portion of the leaf blade was removed by cutting the apical section of the blade with scissors, the leaf area removed was an estimate based on the proportion of laminar removed. To ensure that the reduction in leaf area was as close as possible to that required, leaves from non-treatment trees were cut according to the required degree of damage and both sections of leaf run through a Patons Electronic Planimeter to check the proportion removed. Leaf samples from these measurements were taken into the field as templates when applying treatments. In simulating 100% damage (equivalent to complete defoliation) the entire leaf blade was removed by cutting through the petiole.

Trial 1: this trial consisted of two simulated leaf damage treatments: removal of either 50 or 100% of entire leaves, and an untreated control. Treatments were applied at FB.

Trial 2: either 20%, 40%, 60%, 80%, or 100% of the leaf blade was removed by cutting as described above. Additional treatments included removal of whole spur leaves, or removal of terminal shoot whole leaves, and an untreated control. All treatments were applied at FB.

Trial 3: treatments were a factorial combination of degree of leaf damage (0, 25, 50, 75, or 100% of the leaf blade removed, or removal of spur/bourse shoot leaves (Appendix 4)) applied at three times (FB, 1 wAFB or 2 wAFB). An untreated control was also included.

2.2: Assessments

Fruit set counts were undertaken in early December of each year and fruit was harvested in March of each season for all trials. The 'Delicious' trees (trials 1 & 2) were strip picked. However, following the normal commercial practice for 'Gala' in trial 3, this cultivar was selectively picked, based on colour, with three picks in total. Number of fruit from each pick was recorded and added together to give total number of fruit per tree. The percentage of fruit harvested at first pick was calculated.

Following grading as described in Chapter 3, the percentage of fruit ≥ 75 mm diameter was determined for each trial.

Fruit samples were examined for L/D ratio, TSS content, fruit firmness and seed number as described in Chapter 3. Starch content and fruit background colour were measured in 'Gala' as described in Chapter 3.

2.3: Data analysis

Data were analysed by analysis of variance as described in Chapter 3.

3. Results

3.1: Trial 1 - Oregon Spur 'Delicious'

Crop load in this trial was relatively low (Table 8.1), with number of fruit/cm^2 TCSA on the controls falling within the target crop load range, and number of fruit/100 blossom clusters being below the target crop load range. Both crop load variables were significantly reduced by the 100% leaf removal treatment, while the 50% treatment had no effect compared with the control.

Mean fruit weight (Table 8.1) and percentage fruit ≥ 75 mm diameter (Table 8.2) were both reduced significantly by the 100% defoliation treatment compared with the control. Fruit in both the control and 50% defoliation treatments were above the commercial target level for mean fruit weight, but fruit from the 100% defoliation treatment was below the target level.

***Table 8.1**: The effect of level of simulated leaf damage on crop load and mean fruit weight of 'Delicious' apple (Trial 1). TCSA, trunk cross-sectional area.*

Amount of leaf removed	No. fruit per cm^2 TCSA	No. fruit per 100 blossom clusters	Mean fruit weight (g)
Control	3.93	25	181
50%	3.59	24	184
100%	0.27	2	106
LSD (P=0.05)	0.75	5	43
Commercial target levels	*2-4*	*40-60*	*150*

Return bloom was significantly lower in the 50% treatment than in the control or 100% treatment (Table 8.2).

Fruit L/D ratio (Table 8.3) was significantly reduced by the 100% treatment compared with the other two treatments, but TSS, fruit firmness and seed number were significantly higher in the 100% treatment than in both the control and 50% treatment.

***Table 8.2**: The effect of level of simulated leaf damage on fruit size (% fruit ≥ 75 mm diameter) and return bloom of 'Delicious' apple (Trial 1). TCSA, trunk cross-sectional area.*

Amount of leaf removed	% fruit ≥ 75 mm diameter	Return bloom (buds per cm^2 TCSA)
Control	69	18
50%	78	8
100%	30	19
LSD (P=0.05)	14	6

***Table 8.3**: The effect of level of simulated leaf damage on fruit shape (length/diameter ratio), sugar content, firmness and seed number of 'Delicious' apple (Trial 1).*

Amount of leaf removed	Fruit length/diameter ratio	Total soluble solids (°Brix)	Fruit flesh firmness (kg)	Average number of seeds per fruit
Control	0.985	13.46	11.34	4.8
50%	0.980	13.49	11.42	4.9
100%	0.962	13.95	11.78	7.6
LSD (P=0.05)	0.014	0.04	0.25	0.7

3.2: Trial 2 - Oregon Spur 'Delicious'

Compared with the control, the only treatments to significantly reduce crop load were the 100% leaf removal and the spur leaf treatment (Table 8.4). Crop loads were above the commercial target range for all treatments except for the 100% defoliation and spur leaf treatments. Mean fruit weight was significantly increased by the 20%, 60%, 80%, 100% and spur leaf treatments. The spur leaf treatment was the only treatment to show a significant increase in the number of fruit ≥ 75 mm diameter.

Return bloom was low in all treatments, with only 2.5 buds/cm^2 TCSA in the control (Table 8.5), but 100% leaf removal had significantly greater return bloom than the control. Fruit sugar content was significantly increased by most leaf removal treatments, however the 40% treatment reduced sugar levels, while the 20% defoliation and terminal leaf removal had no effect. Removal of spur leaves resulted in the greatest increase in fruit sugars. All treatments significantly reduced fruit firmness compared with the control with the exception of the 100% treatment. The 80% and spur treatments had reduced seed numbers compared with the control.

***Table 8.4**: The effect of level of simulated leaf damage on crop load and mean fruit weight and size of 'Delicious' apple (Trial 2). TCSA, trunk cross-sectional area.*

Amount of leaf removed	No. fruit per 100 blossom clusters	No. fruit per cm^2 TCSA	Mean fruit weight (g)	% fruit ≥ 75 mm diameter
Control	84	6.46	106	2
20%	76	7.13	134	7
40%	63	5.75	113	2
60%	60	5.67	144	5
80%	67	4.59	148	12
100%	12	1.09	140	13
spur leaves	36	3.63	156	23
terminal leaves	67	7.09	126	3
LSD (P=0.05)	*35*	*2.19*	*26*	*11*
Commercial target levels	*40-60*	*2-4*	*150*	

***Table 8.5**: The effect of level of simulated leaf damage on return bloom, fruit sugar content, firmness and seed number of 'Delicious' apple (Trial 2). TCSA, trunk cross-sectional area.*

Amount of leaf removed	Return bloom (buds per cm^2 TCSA)	Total soluble solids (°Brix)	Fruit flesh firmness (kg)	Average no. of seeds per fruit
Control	2.5	13.48	7.61	6.4
20%	3.6	13.82	7.24	5.9
40%	1.6	13.27	7.20	5.9
60%	1.1	13.67	7.23	6.1
80%	2.9	13.78	7.40	5.7
100%	8.6	13.64	7.53	6.5
spur leaves	6.2	14.17	7.29	5.0
terminal leaves	1.4	13.97	7.12	6.4
LSD (P=0.05)	*3.8*	*0.17*	*0.18*	*0.58*

3.3: Trial 3 – 'Royal Gala'

There were no significant interactions between level and time of damage for number of fruit/100 blossom clusters, mean fruit weight, % fruit ≥ 75 mm diameter, return bloom, % fruit harvested at first pick or fruit L/D ratio (results not presented). Both factors had a significant effect on the % fruit ≥ 75 mm diameter and return bloom (Table 8.6(i),(ii)), while level of leaf damage had a significant effect on number of fruit/100 blossom clusters, mean fruit weight, % fruit ≥ 75 mm diameter, return bloom (Table 8.6(i)), % fruit harvested at first pick and fruit L/D ratio (Table 8.7). Interactions for all other parameters examined (number of fruit/cm^2 TCSA, TSS, fruit firmness, seed number, background skin colour, starch index) were significant (Table 8.8).

Compared with the control, number of fruit/100 blossom clusters was significantly reduced at all levels of leaf damage (Table 8.6(i)). The greatest reduction was observed with complete defoliation. Mean fruit weight and % fruit ≥ 75 mm diameter were significantly higher at 75% and 100% damage and spur/bourse leaf removal compared to the other three levels of damage.

Leaf damage occurring 2 wAFB resulted in significantly lower levels of fruit ≥ 75 mm diameter than at FB (Table 8.6(ii)). Return bloom was also lower in the 2 wAFB treatments than the FB treatments.

As shown in Table 8.7, complete defoliation resulted in a significantly higher percentage of fruit harvested at first pick than in any other treatment. But 50% defoliation reduced the amount of fruit harvested at first pick compared with the control and 75% defoliation treatments. The only level of defoliation to significantly affect fruit L/D ratio was 50%. As fruit set was extremely low in the 100% defoliation treatments, there was insufficient fruit available for analysis of fruit quality parameters for these treatments.

***Table 8.6**: The effect of (i) level and (ii) time of leaf damage on number of fruit/100 blossom clusters, mean fruit weight, size (% fruit ≥ 75 mm diameter) and return bloom of 'Royal Gala' apples (Trial 3). TCSA, trunk cross-sectional area.*

	No. fruit per 100 blossom clusters	Mean fruit Weight (g)	% fruit ≥ 75 mm diameter	Return bloom (buds/cm^2 TCSA)
(i) Level of leaf damage				
0% (control)	146	120	15	4.2
25%	101	118	19	4.5
50%	99	125	27	4.1
75%	70	141	53	7.4
100%	3	134	64	13.5
Spur/bourse	70	140	49	9.8
LSD (P=0.05)	*43*	*13*	*16*	*2.4*
(ii) Time of damage				
FB	-	-	44	8.4
1 wAFB	-	-	40	7.1
2 wAFB	-	-	30	6.2
LSD (P=0.05)	-	-	*11*	*1.7*

***Table 8.7**: The effect of level of leaf damage on percentage of fruit harvested at first pick and fruit shape (length/diameter ratio) of 'Royal Gala' apples (Trial 3).*

	% fruit harvested at first pick	Fruit length/diameter ratio
0% (control)	44	0.888
25%	32	0.889
50%	25	0.869
75%	56	0.879
100%	100	-
Spur/bourse	51	0.894
LSD (P=0.05)	*16*	*0.007*

The number of fruit/cm^2 TCSA was significantly reduced compared with the control by 75% and 100% defoliation at all times and by removal of spur/bourse leaves at FB (Table 8.8). Loss of spur/bourse leaves at FB resulted in significantly lower crop load than loss at 1 or 2 wAFB. The 100% defoliation treatments at 1 and 2 wAFB resulted in complete loss of crop, while at FB crop load was significantly lower than at other rates of defoliation.

Fruit TSS content was significantly higher in the spur/bourse leaf defoliation treatments than in the control (Table 8.8). The 75% defoliation treatments at 1 and 2 wAFB also increased fruit TSS levels significantly compared with the control. Fruit TSS levels were significantly lower than the control in all 25% treatments and in the 1 wAFB 50% treatment.

There was a significant increase in fruit firmness compared with the control following 75% defoliation at 1 and 2 wAFB, and 50% defoliation treatment at 2 wAFB. Firmness was significantly lower than the control in the 75% FB and spur/bourse FB and 1 wAFB treatments.

Compared with the control, seed number was significantly reduced by 25% defoliation 2 wAFB, but was significantly higher in the 75% FB and the spur/bourse FB and 1 wAFB treatments.

***Table 8.8**: The interaction between level and time of simulated leaf damage on crop load, fruit sugar content, flesh firmness and seed number of 'Royal Gala' apple (Trial 3). TCSA, trunk cross-sectional area.*

Time of leaf removal	Amount of leaf removed	No. fruit per cm^2 TCSA	Total soluble solids (°Brix)	Fruit flesh firmness (kg)	Average no. seeds per fruit
Control	0%	10.69	12.81	10.89	3.7
FB	25%	13.65	12.33	10.82	3.8
	50%	10.53	12.88	10.72	3.3
	75%	7.15	12.83	10.28	4.5
	100%	0.89	-	-	-
	spur/bourse	3.54	13.19	10.33	4.8
1 wAFB	25%	7.37	12.65	10.87	3.0
	50%	8.08	12.43	10.78	4.1
	75%	5.33	13.00	11.43	3.0
	100%	0.00	-	-	-
	spur/bourse	7.78	13.03	10.51	4.7
2 wAFB	25%	8.58	12.50	10.56	2.8
	50%	8.45	12.85	11.39	3.4
	75%	3.95	13.05	11.82	3.7
	100%	0.00	-	-	-
	spur/bourse	7.51	13.17	11.00	3.5
LSD (P=0.05)		*3.53*	*0.09*	*0.33*	*0.7*

As shown in Table 8.9, there was no significant effect on fruit skin background colour with 50% defoliation at all times or 75% at 2 wAFB compared with the control. Background colour was greener in all 25% defoliation treatments and the 75% at FB treatment than in the control. The 75% 1 wAFB and 1 and 2 wAFB spur/bourse treatments all resulted in significantly yellower fruit than the control. At 2 wAFB, the greater the level of leaf removal the more yellow the fruit

Only one treatment, 25% defoliation at 2 wAFB, resulted in a significantly lower starch index than the control (Table 8.9). Removal of spur/bourse leaves at both 1 and 2 wAFB significantly increased the starch index compared with the control, as did 25% and 75% defoliation at FB.

Table 8.9: *The interaction between level and time of simulated leaf damage on fruit background skin colour and starch index of 'Royal Gala' apple (Trial 3).*

Time of leaf removal	Amount of leaf removed	Background skin colour	Starch index
Control	0%	3.7	2.7
FB	25%	3.0	3.5
	50%	4.0	2.9
	75%	3.2	3.1
	100%	-	-
	spur/bourse	3.2	2.6
1 wAFB	25%	3.3	2.6
	50%	3.4	2.6
	75%	4.1	2.7
	100%	-	-
	spur/bourse	4.1	3.1
2 wAFB	25%	3.1	2.1
	50%	3.7	3.0
	75%	4.0	2.6
	100%	-	-
	spur/bourse	4.1	3.2
LSD (P=0.05)		*0.3*	*0.3*

4. Discussion

This work has demonstrated that apple trees will tolerate moderate leaf damage during the flowering period with no significant effect on fruit set and thus crop load.

High levels of damage (≥ 75%) impacted on fruit quality, but low levels of damage had little effect.

Fruit set is influenced by the time that leaf damage occurs, as well as the degree of damage. Llewelyn (1968) reported an increase in fruit drop after petal-fall following defoliation at pink bud stage of flowering, but defoliation from 14 days after full bloom had no effect on fruit drop. It was concluded that only damage to spur leaves causes a reduction in crop load. In the work reported here, complete loss of leaves up to 2 weeks after full bloom resulted in very low or no fruit set in all trials. Spur leaves were also shown to be critical for fruit set, while loss of terminal shoot leaves had no effect. This agrees with the conclusions of Ferree and Palmer (1982) that spur leaves on fruiting trees have an important localised influence on fruit set. Their work indicated that fruits are very dependent on leaves within the spur early in the season and are unable to receive photosynthate from elsewhere in the tree. However, Llewelyn (1963) found differences among apple cultivars, with 'Cox's Orange Pippin' and 'Worcester Pearmain' appearing much more dependent upon the spur leaves than 'Laxton's Superb'. Studying spray damage by lime-sulphur, Llewelyn (1963; 1966) concluded that the visible damage done to the spur leaves by two pre-blossom sprays of 2.5% lime-sulphur was insufficient to have any effect on fruit retention. This evidence, in conjunction with the results in the present work, suggests that the marginal burning of leaves frequently observed following application of desiccants for fruit thinning is unlikely to have any detrimental effects on fruit set.

Fruit weight is normally inversely related to crop load (Jones *et al*. 1992b). However, following complete defoliation in this study, fruit weight did not increase in proportion to the reduced crop load observed. In trial 1, fruit weight was reduced following complete defoliation, while in trials 2 and 3, although there was an increase in fruit weight above that observed in the control, the expectation would have been for considerably heavier fruit considering the light crop loads. Although Proctor and Palmer (1991) reported no effect of early season defoliation on mean fruit weight, Lakso *et al.* (1996) reported reduced fruit growth rates in Starkrimson 'Delicious' trees following European red mite injury of leaves. The results reported in the present study suggest that complete loss of leaves and the associated lack of production of assimilates has a major impact on cell numbers within the fruit, and hence on final fruit weight at harvest. Combined with the impact on fruit set discussed above, complete loss of leaves during the flowering period had a marked effect on crop production with low yield and reduced fruit weights.

In this study, there was no effect on fruit weight or size at leaf loss levels of 50% up to 2 weeks after full bloom. Partial defoliation has been shown to cause changes in the pattern of distribution of assimilates from the remaining leaves, compensating for the loss of part of the photosynthetic system (Quinlan 1966). However, Paval and Dejong (1993) concluded that limiting carbohydrate export from leaves, naturally or artificially induced, reduces fruit size and quality in peach. While it is likely that fruit weight/size is influenced by both the degree and timing of damage, other factors such as temperature and incident radiation can also affect fruit size (Doud and Ferree 1980; Wagenmakers and Callesen 1995), and this may explain the difference in effect on fruit size in the first year trial.

Other reported effects of leaf damage caused by mites and other foliar feeders on apples include poor fruit colour, reduced sugar concentrations, and delayed maturity (Ames *et al.* 1984; Beers *et al.* 1987). Effects on fruit firmness of ‘Braeburn’ by both whole and half-tree defoliation have also been reported (Davis *et al*. 2000). The work reported here confirmed previous reports that loss of leaf area affects fruit firmness, but in addition, it also showed differences between cultivars. In ‘Delicious’ fruit firmness was reduced by high levels of leaf damage in both trials, however in ‘Gala’, there was an increase in fruit firmness with increasing levels of leaf damage. This agrees with the findings of Zwick *et al*. (1976) who reported differences between the cultivars ‘Newtown’ and ‘Golden Delicious’ when examining the impact of mite damage on fruit firmness.

This study showed some variation in the effect of leaf loss on fruit soluble solids concentrations. In the first year 'Delicious' trial, soluble solids were reduced following 100% defoliation , while 50% leaf damage had no effect. This agrees with the findings of Marini *et al*. (1994) who reported that soluble solids concentration declined with increasing levels of mite damage. However, in this study both subsequent trials showed an increase in fruit TSS with increasing levels of leaf damage up to 2 weeks after full bloom. Hudina and Stampar (2000) also reported decreased soluble solids in pear (*Pyrus communis* L.) with a 30% reduction in leaf area 4 weeks before harvest. Hence it appears that soluble solids concentration of fruit is affected by both level and time of leaf damage. In simulating defoliation by pests, DenHerder and Rom (1991) found that 50% leaf removal 8 to 14 weeks after bloom had no effect on fruit soluble solids. It is however, difficult to explain the increased soluble solids with reduced leaf area, one explanation for this is an increase in fruit maturity brought about indirectly as a result of lower crop load levels in these treatments.

Although there was an effect on seed numbers in this study, there was variation in results between trials. The only conclusion that can be drawn from this work is that healthy spur leaves early in the season appear to be important for seed development.

Fruit red skin colour was increased in 'Gala' trees subjected to 50% leaf loss or greater from full bloom to 2 weeks after full bloom. Both Ames *et al*. (1984) and Marini *et al*. (1994) reported reduced red skin colour with increasing mite damage, but these authors only specified mite loads, not at what part of the season most damage occurred. Reports on the effects of leaf damage on fruit background skin colour or starch levels are lacking. In this study, background skin colour and starch index ratings in 'Gala' suggested that greater foliar damage levels up to 2 weeks after flowering accelerated fruit maturity at normal harvest time for controls. Both fruit background colour and starch levels are standard indicators of fruit maturity. This work suggests that damage to spur leaves from 1-2 weeks after full bloom tends to bring fruit maturity forward.

Fruit length/diameter ratios were reduced in both ‘Delicious’ and ‘Gala’ by high levels of leaf damage, but there was no effect at low levels of damage. Fruit shape is important in all cultivars, but anything that affects fruit typiness of ‘Delicious’ apples will result in a major marketing disadvantage (Williams and Stahly 1969; Veinbrandts 1979).

The results reported here have demonstrated that leaf damage during flowering may affect fruit quality to varying degrees, however the severity of the effect on fruit quality may depend on crop load. Both Marini *et al.* (1994) and Francesconi *et al.* (1996) reported greater decreases in fruit size, colour, and soluble solids concentration in damaged trees with heavy crops than in lightly cropped trees. Ames *et al*. (1984) also reported that deleterious effects of mite feeding increased with increasing fruit load. Zwick *et al*. (1976) suggested that vigorously growing, non-stressed apple trees were relatively tolerant of leaf damage by mites without adverse affects, and Hoyt *et al*. (1979) concluded that apple trees suffering from moisture stress were prone to experience greater effects from mite injury. Hence it is likely that healthy balanced trees will tolerate a higher level of leaf damage, whatever the cause, than stressed, poorly growing trees. It has also been postulated that the variation in results between individual studies may be due to differences in the environment, the timing and severity of mite stress, and the physiological status of the tree (Francesconi *et al.* 1996).

Reports on the effect of defoliation and/or leaf damage on return bloom are conflicting (Lienk *et al.* 1956; Beers *et al.* 1987; Beers and Hull 1987; 1990; Hull and Beers 1990; Lakso *et al.* 1996). Beers and Hull (1987) also reported differing responses between cultivars. The results of this work, where return bloom was generally higher where crop load was reduced, suggest that the level of return bloom may be related to crop load and is not necessarily a direct result of loss of leaf area up to 14 days after bloom. When leaf area is reduced at flowering, growth of new leaves ensures that the supply of current photosynthate is replaced before flower initiation for the following season occurs and thus explains why early season leaf damage has little or no impact on subsequent flowering.

Proctor and Palmer (1991) found that, while spur leaves were not necessary for flower initiation and expression, removal of bourse leaves had a dramatic effect in reducing return bloom in the three cultivars they studied. They also cited references by Ramirez (1979) and Hoad and Abbott (1986) showing that removal of bourse leaves of 'Cox' almost eliminated subsequent flowering. Work by Davis *et al*. (2000) confirmed this finding. This present study confirms the findings of Proctor and Palmer (1991) in relation to spur leaves.

Chapter 9

General Discussion

1. Introduction

As reviewed earlier (Chapter 2) fruit quality and yield are influenced by a complex interaction of factors, some fixed by decisions made at planting and others variable with management and environment from season to season. Careful planning to include a consideration of site, cultivar and rootstock, training system, row orientation, and tree spacing within and between rows before orchard establishment, can optimise the impact of 'fixed' factors on yield and fruit quality. Once the orchard is established, productivity and fruit quality can be regulated to a large degree by the management practices implemented by the grower. As both regular and consistent crop yield and fruit pack-out percentages are important for orchard profitability, awareness of factors that can improve fruit quality and production efficiency, enabling growers to increase the base level of pack-out by minimising fruit consigned to processing, will ensure that economic sustainability is maintained.

In the absence of significant plant health issues, crop yield and quality are primarily determined by year to year management decisions on crop regulation through pruning and thinning, whether by hand or chemical. The research presented here provides a substantial framework for improving base pack-out levels under Australian conditions. In particular, it targets the influence of pruning and recent developments in chemical thinning on fruit quality, with emphasis on the effects of exposure to and interception of incident light for both leaves and fruit at various stages in development.

2. Crop load – pruning and thinning

Both the degree and timing of pruning have an effect on fruit size and quality. This work, detailed in Chapter 4, has shown that the increasing tendency of

Australian growers to delay pruning until after fruit set, rather than completing it while the trees are still dormant, may result in reduced fruit quality. At harvest, spring pruned trees produced poorly shaped (flatter) fruit with reduced sugar levels and increased russet. Although further work is required, the result suggests that early pruning results in an increase in fruit cell numbers due to greater availability of resources to the developing fruit.

Pruning is also an important component of crop load management as described by Jones *et al*. (1998), and this study has demonstrated that the level of pruning is more important than time of pruning in reducing crop load. Under Australian conditions, trees tend to set heavily and reducing crop load at fruit set can be difficult. Hence the ability to start the reduction of potential flowers by pruning is an early strategy, completed during the dormant period. This could be of considerable benefit to growers.

In Chapter 6, optimum crop loads varied with cultivar, however, if fruit is thinned during flowering or during the early phase of fruit development, large fruit can be obtained at higher crop loads. As climatic differences between years can also impact on fruit quality, seasonal weather patterns during the early spring period should be taken into account when determining final crop loads during hand-thinning.

The current target crop load recommendation by Koen *et al*. (1988) of 2-4 fruit/cm^2 TCSA for 'Delicious' is confirmed by this study. For 'Fuji', crop loads of 4-6 fruit/cm^2 TCSA, as suggested by Jones *et al*. (1992b), will produce large fruit of 200 g or more, but if thinning is delayed crop loads need to be reduced in order to achieve fruit of this size. In this study, fruit size declined in both 'Pink Lady' and 'Gala' at crop loads above 6 fruit/cm^2 TCSA. Therefore the recommended target crop load for both these cultivars should be in the range 4-6 fruit/cm^2 TCSA.

Early thinning also had a positive effect on fruit quality. The positive relationships between fruit sugar content and weight and between fruit firmness and weight in both 'Fuji' and 'Delicious', and between fruit sugar content and fruit firmness in 'Delicious' have not been demonstrated previously and demonstrate that early thinning is a valuable tool in improving fruit quality. Early thinning also means that photosynthates produced by the tree are directed into the fruit that will remain on the tree, maximising resources during the cell division period in the first six weeks after bloom.

Rootstock effects were also evident, with the dwarfing rootstock M26 producing superior quality fruit and improved return bloom compared with the semi-vigorous MM106. Talaie *et al*. (2004) observed a higher yield efficiency with M26 rootstocks compared with MM106, however these authors reported that rootstock had no noticeable effect on fruit quality. It appears from this present study that rootstock can affect fruit quality, and this effect is independent of crop load or fruit size. Although rootstock is a fixed factor which growers are unable to alter after planting, awareness of the impact of rootstocks on fruit quality will assist growers in the orchard establishment phase, and also in management of crop load season by season.

As discussed previously, it is important for growers to have a range of tools available for reducing excessive crop loads in an efficient and timely manner. The desiccating chemicals, ammonium thiosulphate and potassium thiosulphate, studied in Chapter 7 demonstrated effectiveness as thinning agents with no adverse affects on fruit quality. Registration of desiccants such as these will provide growers with an alternative to the current hormonal types of blossom thinners, NAA and ethephon, both of which can be unreliable in the unpredictable spring weather conditions experienced in most Australian apple growing regions (Jones *et al*. 1998).

In addition to confirming the effectiveness of ATS as a blossom thinner, this study has demonstrated positive effects of ATS on fruit size and other quality parameters. The previously reported negative effects of crop load on fruit weight and size (Jones *et al*. 1992b; McArtney *et al*. 1996; Webster 1997) were clearly demonstrated in this work, both in the studies conducted with ATS and in the crop load studies reported in Chapter 6. However, it was also demonstrated that high crop load has a negative effect on both fruit sugar content and firmness. Again, this finding was consistent across the ATS and crop load studies. The positive relationships between fruit weight and sugar content and between fruit weight and firmness demonstrated in both the ATS and crop load studies show that, as long as trees are regular bearing and are thinned early in the season, large fruit can be of high quality. This evidence dispels the myth that large fruit tends to be of poor quality (Fidler *et al*. 1973).

ATS is most effective as a blossom thinner when applied twice during the blossom period, with the first application at 20% bloom and the second at 80% bloom. This is similar to the recommended application timings for the desiccant endothal (Bound and Jones 1997; Bound 2001a). The recommended application rate for ATS should be 1.0% v/v, as higher rates showed no additional advantages.

ATS can also be effectively combined in a program with the post-bloom thinner CyLex, giving growers another option when determining their thinning programs. Addition of CyLex to the spray program has the added benefits of increasing fruit weight, size, firmness and sugar content over and above the levels achieved with ATS alone. As previously discussed, CyLex increases the number of cells in the fruit when applied during the cell division period, resulting in larger firmer fruit size.

With the phasing out of many successful chemical thinners throughout the history of chemical thinning as a result of increased environmental and public health concerns (Bound 2001b), there is room for chemicals that are considered benign. Although ammonium thiosulphate is considered to be a safe chemical, it contains ammonia which is not acceptable to organic growers and which may also, in the future, become a targeted chemical in conventional growing. Thus an examination of potassium thiosulphate was considered worthwhile.

Used as a desiccant blossom thinner, potassium thiosulphate showed similar promise to ammonium thiosulphate in terms of both fruit quality and as a method of managing crop load. From the preliminary results obtained in Chapter 7, further work is justified to confirm the efficacy of potassium thiosulphate across a range of cultivars and to determine the most effective number of applications for each cultivar. Its effect on fruit quality and fruit storage life should also be examined in more detail. Two applications at a rate of 0.5% or 1.0 % (v/v) appear to be suitable for 'Delicious' which has a relatively short flowering period. However, for the longer flowering 'Royal Gala' at least three applications appear to be necessary. With a third application, it is likely that a lower rate would achieve similar or better results than achieved by two applications at 1.5% with no adverse effects of high concentrations. Potassium thiosulphate at 0.5% or 1.0% appears to have no detrimental effects on fruit quality, other than a slight flattening effect. This effect, however, is not as marked as that produced by ethephon (Bound *et al*. 1993a), a chemical that is currently widely used as an apple thinner. A reduction in fruit firmness evident at the higher rate of application can be avoided using the dual application at lower rates.

3. Light – incidence and interception

The most commonly used method of manipulating light interception or distribution within the canopy is summer pruning. Reports in the literature (Perring and Preston 1974; Terblanche and Pienaar 1977; Utermark 1977; Lord and Greene 1982; Marini and Barden 1982; Katzler and Wurm 1998) relating to summer pruning are conflicting, predominantly due to variations in time, degree and method of pruning. This study (Chapter 4) has clarified the impact of summer pruning (i.e. removal of current season's growth) on fruit quality. Although summer pruning is commonly used to improve fruit colour, the results presented demonstrate that it can adversely affect fruit size, sugar content and skin finish. Seeley *et al*. (1980) suggested that, while it is a common practice to grade fruit based on red skin colour development, fruit graded as high quality based on red colour is not necessarily the highest quality fruit in terms of size, sugar content or starch. This observation, combined with the evidence presented here, suggests that a change in cultural practices to reduce excess vegetative growth, and thus the need for summer pruning would, in the longer term, result in higher overall fruit quality.

The results from Chapter 5 indicate that shading of trees during early fruit development reduces both crop load and fruit size, which concurs with earlier conclusions by Jackson and Palmer (1977a; 1977b). A significant reduction in both crop load and fruit size has a negative impact on yield. As reduced fruit size is likely to result from light-limited photosynthesis and an associated reduction in carbohydrate assimilation during the critical cell division phase (Jackson and Palmer 1977b), any overall effect on yield as a result of a reduction in fruit size caused by shading can be ameliorated by ensuring excess fruit are removed during the flowering period, or soon after. This enables the limited resources produced under shaded conditions to be directed into those fruit remaining on the tree, thus maximising resources during the period of cell division. Jackson *et al*. (1977) demonstrated that reduced fruit size caused by shading is a result of reductions of cell size and number of cells per fruit. This explains the lack of effect on fruit size with later shading in the present study, as cell numbers in fruit are determined by around 6 weeks after bloom (Webster 1997). While the level and time of shading in relation to the stage of fruit development and tree growth influence fruit set, this study demonstrated that the small degree of shading caused by white hail netting (17% reduction in incident radiation) had a minimal effect.

In addition to the competition between developing fruit for carbohydrates (Lakso *et al*. 1995), vegetative growth also competes with developing fruit (Jackson and Palmer 1977a; 1977b; George *et al*. 1996). Hence it is particularly important under shaded conditions that appropriate pruning strategies are used to minimise excessive shoot growth which may contribute to reduced fruit size (Middleton and McWaters 2002).

Consistent effects of netting on TSS have been difficult to quantify, and the results obtained in this study are in keeping with the conflicting reports from other authors. Middleton and McWaters (2002) have suggested that fruit size and the location of apples within the tree canopy can both confound any effect of netting on sugar content and make it difficult to directly attribute differences in fruit TSS to hail netting.

The effect of shade on fruit firmness has not been clarified in this study. The results are similar to the conflicting findings of other authors, and support the conclusions of both Widmer (2001) and Stampar *et al*. (2002) that fruit firmness is influenced by many factors that over-ride the shading effect produced by netting.

Both sugar content and firmness are used as indicators of fruit maturity, and some of the conflicting results obtained in this study could well be simply a reflection of differences in stages of maturity. Widmer (1997) reported that increased firmness and acidity under netting indicated delayed ripening, and Middleton and McWaters (2002) also reported that the maturity of apples was delayed under black netting.

Covering fruit with bags improved fruit skin finish with the effect related to time of application. Growers in Japan have successfully used this technique to produce a uniformly coloured, blemish-free fruit that commands a high price in specialty markets (Proctor and Lougheed 1976). The present study demonstrates that the earlier in the season fruit is covered, the more likely that fruit skin damage will be prevented. Although fruit sugar content was reduced by bagging later in the season, these fruit also showed increased levels of starch and firmness compared with fruit bagged at 2-4 wAFB. Further work is required to determine whether this is an effect of delayed maturity or whether bagging, although producing well coloured fruit with high visual appeal, does produce inferior fruit in terms of sugar content, firmness and flavour as suggested by Robinson (1974).

Results from Chapter 8 demonstrate that low levels of foliar damage during the flowering period had little effect on fruit size or quality, but where 75% or more of the leaf surface was lost, fruit quality was affected and fruit set reduced. Llewelyn (1968) stated that, while the degree of damage is important, the time that leaf damage occurs also influences fruit set, and thus crop load. Leaf damage during flowering affected fruit quality to varying degrees, with higher levels of damage, particularly to spur leaves, bringing fruit maturity forward. High levels of leaf damage also reduced fruit size, in spite of reduced crop load levels. As discussed previously in relation to overhead shading of trees (Chapter 5), a reduction in carbohydrate assimilation during the cell division phase of fruit development is likely to reduce fruit size. Quinlan (1966) reported that partial defoliation causes changes in the pattern of distribution of assimilates from the remaining leaves, compensating for the loss of part of the photosynthetic system. This would explain the lack of effect in this study of low levels of defoliation, however at higher levels of defoliation (≥ 75%) it would appear that the trees are unable to compensate sufficiently to cope with the loss of photosynthetic surface.

In the work reported here, complete loss of leaves up to 2 weeks after full bloom resulted in very low or no fruit set in all trials. Spur leaves were also shown to be critical for fruit set, while loss of terminal shoot leaves had no effect on crop load, agreeing with the conclusions of Llewelyn (1968) and Ferree and Palmer (1982) that spur leaves on fruiting trees have an important localised influence on fruit set.

This study confirmed that loss of leaf area affects fruit firmness (Davis *et al*. 2000), but it also showed differences between the two cultivars studied. Fruit firmness in 'Delicious' was reduced by high levels of leaf damage, while in 'Gala', increasing levels of leaf damage increased fruit firmness.

This study has demonstrated that the level of foliar damage resulting from the application of desiccating chemicals used as blossom thinners during the flowering period is unlikely to have any detrimental affect on fruit quality, as foliar damage is minimal at the recommended application rates. This should allay grower concerns relating to the impact of blossom desiccants on fruit quality.

4. Conclusions

In addition to demonstrating that management practices can influence fruit quality as well as fruit set, and thus crop load, this study has also confirmed that the first few weeks after flowering, i.e. the cell division phase of fruit development and growth, is important in determining final fruit quality. Martin *et al*. (1964) have discussed the importance of keeping cell size to a minimum in order to achieve the commercial aim of producing large fruit with good storage capacity. According to these authors, this implies that cell numbers need to be as high as possible to achieve this aim. As cell numbers are determined within the first 4-7 weeks of fruit development (Smith 1950; Bain and Robertson 1951; Webster 1997; Stanley *et al*. 2000), any factor or activity that results in a reduction in available photosynthate for each developing fruit during this period is a critical determinant of quality. Management practices that involve shading of trees, pruning during the growing period, late season thinning or leaf damage either reduce the amount of photosynthate produced, reduce carbohydrate reserves or result in increased competition from other sinks during the cell division phase of fruit development. According to Priestley (1962), growing fruits use carbohydrates from regions of both synthesis and storage, hence carbohydrate is a limiting factor to fruit development. Early fruit growth, when leaf area is low, would be expected to be dependent on reserves, rather than on the current products of photosynthesis, as leaves only begin to balance demand with production when they reach about half their full size (Priestley 1962). Martin *et al*. (1964) concluded that the major factor controlling cell numbers in apple fruits is the reserves available from the previous season.

In terms of both crop load and fruit size, level of pruning is more important than time of pruning. Light pruning leaves more flowering spurs on the tree, resulting in higher crop loads. This means more competition between flowers/fruitlets for resources, whether reserves or current products of photosynthesis, and thus reduced fruit size. Delaying 'dormant' pruning until after flowering adversely impacted on fruit skin finish, sugar content and L/D ratio. As dormant pruned trees tend to be more vigorous early in the season than un-pruned trees, such trees are more likely to have a higher leaf:fruit ratio and hence more available photosynthate for the developing fruits, particularly once leaves are expanded sufficiently to maintain a positive balance of supply over demand. In the later pruned trees, fruit quality in the developing fruit is likely to be already compromised by competition with vegetative growth, as well as by competition with other fruits that are later removed from the tree through pruning. Late pruning and/or thinning effectively waste the trees resources, as growth is put into fruit and/or vegetation that is later removed.

The reduction in fruit weight following early season shading (2 wAFB) compared with no effect when trees were shaded later in the season at 7 weeks after flowering, i.e. after the cell division period, again illustrates the importance of maximising resources during the period of cell division.

Fruit sugar levels were higher in early-thinned fruit than in late-thinned fruit. The positive relationship demonstrated between fruit firmness and weight and between fruit firmness and sugar content with early thinning illustrates additional advantages for early thinning beyond those already established in relation to fruit size. Large fruit can be of better quality than small fruit, providing it is from regular bearing early-thinned trees. This finding shows that fruit from trees thinned to a light crop load is different to fruit from off-year trees, disputing the long held belief that large fruits from lightly cropping trees, regardless of whether off-year or due to early or mid-season fruit thinning, are softer and more susceptible to rotting and storage disorders (Fidler *et al*. 1973). Martin and Lewis (1952) reported that the difference in fruit size between light and heavy crops is due to cell size. The largest volumetric growth rate of fruit occurs during the third phase of growth, and spreads over most of the season after the cell division phase is complete (Magein 1989; Schechter *et al*. 1993). According to Baumann and Henze (1983), fruit growth during this phase is mainly due to enlargement of cortex and pith cells and from the increasing volume of intercellular spaces. As off-year trees tend to be vigorous, producing more vegetative growth than on-year trees (Jones *et al*. 1998), their leaf:fruit ratio is higher than in on-year trees, particularly as the season progresses. This means that there are more resources available to each fruit in off-year trees, enabling greater expansion of cells, regardless of cell number, potentially resulting in larger cell size with larger intercellular spaces, and consequently softer fruit. Westwood *et al*. (1967) also listed healthy leaves as one of the factors that tended to increase cell size.

The use of blossom desiccants for thinning was shown to increase fruit firmness and sugar content. As discussed earlier, thinning during the flowering period increases the leaf:fruit ratio before the cell division phase, as well as reducing the competition between the developing fruits (Lakso *et al*. 1995). The end result is the availability of more resources for each fruit, resulting in greater cell numbers, and thus firmer fruit.

For practical crop management, optimal target crop loads for 'Delicious' of 2-4 fruit/cm^2 TCSA were confirmed in this study. For 'Fuji', if thinning is delayed later than 6 wAFB, crop loads need to be reduced from the 4-6 fruit/cm^2 TCSA suggested by Jones *et al*. (1992b) to 2-4 fruit/cm^2 TCSA in order to achieve large fruit size. Recommended crop loads for other cultivars have been lacking, and this study has demonstrated that for both 'Pink Lady' and 'Gala', crop loads of 4-6 fruit/cm^2 TCSA are ideal targets. As discussed above, reducing fruit numbers at or soon after flowering has the effect of reducing competition for resources between fruit, allowing individual fruit to develop greater cell numbers, thus maintaining fruit firmness, even in larger fruit.

A major finding of this study is that the timing of crop regulation is critical to fruit quality, particularly sugar content and firmness. In addition to the expected negative relationship between crop load and fruit weight/size, crop load also has a negative effect on fruit sugar content and firmness. However, in early-thinned trees, there is a positive relationship between fruit weight and sugar content, and between fruit weight and firmness. Hence strategies such as the use of substantial removal of flower buds in dormant pruning, and application of blossom desiccants early in the flowering period, provide an excellent chance of maximising fruit quality, and thus returns to the grower.

By increasing awareness of the impact of orchard management practices on fruit quality and making appropriate adjustments, the base level of fruit pack-out can be increased with minimal or no additional cost to growers. Pruning during the dormant period should be considered the first stage of the crop regulation program, as recommended by Jones *et al*. (1998), followed by thinning, whether by hand or with chemicals. Many Australian growers are not aggressive with their chemical thinning programs and do not complete hand-thinning until well into December, or even January, however it is important to complete thinning as soon after flowering as practical to produce high quality fruit. When chemical thinning is undertaken, the choice of chemical can influence final fruit quality. Where desiccating chemicals are applied as blossom thinners, the recommended application rates should be adhered to, ensuring that foliar damage is minimised. It is particularly important where netting is used, either for hail or bird protection, that attention is paid to any practices that further limit carbohydrate availability to developing fruit. Management should limit crop loads, and minimise both competition from vegetative growth and foliar damage. Attention to these practices will assist the Australian apple industry to improve production efficiency and cost competitiveness in an increasingly competitive global market.

Chapter 10

References

Abbott, D L (1954) Growth substances as fruit thinning agents for apples. *Report Long Ashton Agricultural Research Station for 1953*, pp 58-63.

ABS (2004) Agricultural Survey: Apples and Pears, Australia. *AusStats 7111.0.55.002*.

ABS (2003) Agricultural Survey: Apples and Pears, Australia. *AusStats 7111.0.55.002*.

Alder, S J (1994) Russeting control takes knowledge of various causes. *Good Fruit Grower*, **45**, 38-39.

Ames, G K; Johnson, D T and Rom, R C (1984) The effect of European red mite feeding on the fruit quality of 'Miller Sturdeespur' apple. *Journal of the American Society for Horticultural Science*, **109**, 834-837.

Andrews, P K and Collier, M L (1995) Chemical thinning of Fuji apple trees. *Good Fruit Grower*, **46**, 21-25.

Anon (1998) Cooling can increase tree's irrigation needs. *Good Fruit Grower*, **49**, 29.

Anon (1988) Growth Regulator Sprays. In: *Washington State University 1988 Spray Guide for Tree Fruit in Eastern Washington, Extension Bulletin 419*, pp 67-77.

Anon (1985) Quality improvement. *Australian Apple and Pear Corporation Annual Report*, 1985, 13-14.

Arthey, V D (1975) Quality of horticultural products. Butterworths & Co., London, 228 pp.

Atkinson, C J; Taylor, L and Kingswell, G (2001) The importance of temperature differences, directly after anthesis, in determining growth and cellular development of *Malus* fruits. *Journal of Horticultural Science & Biotechnology*, **76**, 721-731.

Australian Horticultural Corporation (1993) Guide to quality management: apples. The Australian Horticultural Corporation, Potts Point, NSW, 117 pp.

Autio, W R and Greene, D W (1990) Summer pruning affects yield and improves fruit quality of 'McIntosh' apples. *Journal of the American Society for Horticultural Science*, **115**, 356-359.

Baart, J (1989) Pruning of fruiting wood results in little loss of yield. *Fruiteelt*, **79**, 4, 15.

Bain, J M and Robertson, R N (1951) The physiology of growth of apple fruits. I. Cell size, cell number, and fruit development. *Australian Journal of Scientific Research*, **4**, 75-91.

Barritt, B H (2001) Apple quality for consumers. *The Compact Fruit Tree*, **34**, 54-56.

Baumann, H and Henze, J (1983) Intercellular space volume of fruits. *Acta Horticulturae*, **138**, 107-111.

Beers, E H and Hull, L A (1990) Timing of mite injury affects the bloom and fruit development of apple. *Journal of Economic Entomology*, **83**, 547-551.

Beers, E H and Hull, L A (1987) Effect of European red mite (Acari:Tetranychidae) injury on vegetative growth and flowering of four cultivars of apples. *Environmental Entomology*, **16**, 569-574.

Beers, E H; Hull, L A and Grimm, J W (1987) Relationships between leaf:fruit ratio and varying levels of European red mite stress on fruit size and return bloom of apple. *Journal of the American Society for Horticultural Science*, **112**, 608-612.

Blackburn, D P (2002) Temperature profiles and aspects of radiative exchange under permanent orchard netting. Honours Thesis, Bachelor of Agricultural Science, University of Tasmania.

Blanpied, G D and Wilde, M H (1968) A study of the cells in the outer flesh of developing McIntosh apple fruits. *Botanical Gazette*, **129**, 178-183.

Boucher, W D (1995) Effects of management and site on quality of red Fuji. *Department of Primary Industries and Fisheries, Tasmania. National Red Fuji Seminar*, 24 May 1995.

Bound, S A (2001a) The influence of endothal and 6-benzyladenine on crop load and fruit quality of red 'Delicious' apple. *Journal of Horticultural Science & Biotechnology*, **76**, 691-699.

Bound, S A (2001b) Managing crop load. In: *Crop management and postharvest handling of horticultural products. Volume 1: Quality Management*. Editors: R Dris, R Niskanen and M Jain. Oxford & IBH Publishing Co Pvt. Ltd, New Delhi, India.

Bound, S A (1998) The effect of different adjuvants on the efficacy of the post-bloom thinner CyLex™. Proceedings of the Fifth International Symposium on Adjuvants for Agrochemicals, Memphis, USA. August 17-21, 1998.

Bound, S A and Jones, K M (2004) Ammonium thiosulphate as a blossom thinner of 'Delicious' apple, 'Winter Cole' pear and 'Hunter' apricot. *Australian Journal of Experimental Agriculture*, **44**, 931-937.

Bound, S A and Jones, K M (1997) Investigating the efficacy of endothal as a chemical thinner of red 'Delicious' apple. *Journal of Horticultural Science*, **72**, 171-177.

Bound, S A and Jotic, P (1995) Pruning and russet. *Department of Primary Industries and Fisheries, Tasmania. National Red Fuji Seminar*, 24 May 1995.

Bound, S A; Jones, K M and Oakford, M J (1997) Integrating Cytolin into a chemical thinning program for red 'Delicious' apple. *Australian Journal of Experimental Agriculture*, **37**, 113-118.

Bound, S A; Jones, K M; Graham, B; Oakford, M J and Tichon, M (1993b) Modelling the effects of timing and rates of application of benzyladenine as a secondary thinner of ‘Fuji’ apple after ethephon. *Journal of Horticultural Science*, **68**, 967-973.

Bound, S A; Jones, K M; Koen, T B; Oakford, M J; Barrett, M H and Stone, N E (1991a) The interaction of Cytolin and NAA on cropping red 'Delicious' apple. *Journal of Horticultural Science*, **66**, 559-567.

Bound, S A; Jones, K M; Koen, T B and Oakford, M J (1991b) The thinning effect of benzyladenine on red Fuji apples. *Journal of Horticultural Science*, **66**, 789-794.

Bound, S A; Jones, K M; Oakford, M J and Tichon, M (1993a) Assessing interactive effects between Cytolin and ethephon on cropping red 'Delicious'. *Journal of Horticultural Science*, **68**, 209-213.

Boynton, D and Cain, J C (1943) A survey of the relationships between leaf N, fruit colour, and percent of full crop in some New York McIntosh orchards. *Proceedings of the American Society for Horticultural Science*, **40**, 19-22.

Bramlage, W J; Weis, S A and Greene, D W (1990) Observations on the relationships among seed number, fruit calcium, and senescent breakdown in apples. *HortScience*, **25**, 351-353.

Brookfield, P L; Ferguson, I B; Watkins, C B and Bowen, J H (1996) Seed number and calcium concentrations of 'Braeburn' apple fruit. *Journal of Horticultural Science*, **71**, 265-271.

Bubán, T; Rátz, M B and Oláh, L (1993) Improved fruit shape and less russeting of apples by using gibberellins. *Acta Horticuturae*, **329**, 137-139.

Bukovac, M J and Nakagawa, S (1968) Gibberellin-induced asymmetric growth of apple fruits. *HortScience*, **3**, 172-174.

Bünemann, G (1982) Side-effects of Horticultural practices. *Report East Malling Research Station for 1991,* 175-181.

Byers, R E (1997) Effects of bloom-thinning chemicals on apple fruit set. *Journal of Tree Fruit Production*, **2**, 13-31.

Byers, R E; Barden, J A; Polomski, R F; Young, R W and Carbaugh, D H (1990) Apple thinning by photosynthetic inhibition. *Journal of the American Society for Horticultural Science*, **115**, 14-19.

Byers, R E; Carbaugh, D H; Presley, C N and Wolf, T K (1991) The influence of low light on apple fruit abscission. *Journal of Horticultural Science*, **66**, 7-17.

Byers, R E; Lyons, C G and Yoder, K S (1985) Peach and apple thinning by shading and photosynthetic inhibition. *Journal of Horticultural Science*, **60**, 465-472.

Campbell, J (2002) Apple growing. NSW Agriculture, Agfact H4.1.1, second edition, January 2002.

Campbell, R J and Marini R P (1992) Light environment and time of harvest affect ‘Delicious’ apple fruit quality characteristics. *Journal of the American Society for Horticultural Science*, **117**, 551-557.

Chandler, F B and Mason, I C (1942) Russet of Golden Delicious Apples. *Proceedings of the American Society for Horticultural Science,* **40**, 120-122.

Chen, K; Hu, G Q; Lenz, F and Blanke, M (1998) Apple yield and quality as affected by training and shading. *Acta Horticulturae*, **466**, 53-58.

Chennell, A; Bates, V and Williams, D (2002) Apple maturity management – Training workshop manual. Department of Natural Resources and Environment, Victoria

Childers, N F (1976) *Modern Fruit Science*. 7th ed. Horticultural Publications, Rutgers University, New Brunswick, NJ.

Collins, M (2003) Apple maturity, harvest date and storage potential. *Tree Fruit*, April 2003, 13.

Costa, G; Corelli Grappadelli, L and Bucchi, F (2000) Studies on fruit thinning and growth in apple cultivars [Abstract]. *HortScience*, **35**, 421.

Crassweller, R M (1999) Effects of summer pruning on apples and peaches. College of Agricultural Sciences, Penn State University, Document Number 2940143. Viewed 8 June 2004, <http://www.penpages.psu.edu/penpages_reference/29401/2940143.html>.

Creasy, L L (1980) The correlation of weather parameters with russet of Golden Delicious apples under orchard conditions. *Journal of the American Society for Horticultural Science*, **105**, 735-738.

Creasy, L L and Swartz, H J (1981) Agents influencing russet on 'Golden Delicious' apple fruits. *Journal of the American Society for Horticultural Science*, **106**, 203-206.

Curry, E A (1991) Causes of fruit russeting. *Proceedings of the Eighty-Seventh Annual Meeting of the Washington State Horticultural Association*, 167-169.

Curry, E A and Williams, M W (1983) Promalin or GA_3 increase pedicel and fruit length and leaf size of 'Delicious' apples treated with paclobutrazol. *HortScience*, **18**, 214-215.

Damas, H F (1989) Russet of Golden Delicious apples. *Deciduous Fruit Grower*, **39**, 421-425.

Davis, D E; Barden, J A and Byers, R E (2000) Defoliation affects return bloom, fruit set, and fruit quality of three apple cultivars [Abstract]. *HortScience*, **35**, 482.

DenHerder, M A and Rom, C R (1991) Carbohydrate content, spring growth and bloom of partially defoliated apple trees. *HortScience*, **26**, 174.

Dennis, F G and Nitsch, J P (1966) Identification of gibberellins A_4 and A_7 in immature apple seeds. *Nature*, **211**, 781-782.

Dietz, H J (1984) The effect of summer pruning on growth, yield and fruit quality. *Obstbau*, **9**, 320-321.

Doud, D S and Ferree, D C (1980) Influence of altered light levels on growth and fruiting of mature 'Delicious' apple trees. *Journal of the American Society for Horticultural Science*, **105**, 325-328.

Dražeta, L; Lang, A; Hall, A J; Volz, R K and Kameson, P E (2004) Modelling the influence of seed set on fruit shape in apple. *Journal of Horticultural Science & Biotechnology*, **79**, 241-245.

Dris, R; Niskanen, R and Fallahi, E (1999) Relationships between leaf and fruit minerals and fruit quality attributes of apples grown under northern conditions. *Journal of Plant Nutrition*, **22**, 1839-1851.

Drozdovkii, E M; Gulyaev, A G; Men'shikov, A E (1993) Accumulation of copper preparation in commercial orchards and ways of preventing it [Abstract]. *Sadovodstvo i Vinogradarstvo*, **1**, 8-10.

Ebert, A and Bender, R J (1986) Influence of an emulsifiable mineral oil on the thinning effect of NAA, NAAm, carbaryl and ethephon in the apple cultivar Gala grown in the conditions of southern Brazil. *Acta Horticulturae*, **179**, 667-672.

Eccher, T (1986) Russeting and shape of 'Golden Delicious' apples as related to endogenous GA content of fruitlets. *Acta Horticulturae*, **179**, 767-770.

Eccher, T and Noè, N (1993) Influence of light on shape and quality of Golden Delicious apples. *Acta Horticulturae*, **329**, 156-158.

Elfving, D C and Forshey, C G (1976) Growth and fruiting responses of vigorous apple branches to pruning and branch orientation treatments. *Journal of the American Society for Horticultural Science*, **101**, 290-293.

Fallahi, E and Simons, B R (1996) Interrelations among leaf and fruit mineral nutrients and fruit quality in 'Delicious' apples. *Journal of Tree Fruit Production*, **1**, 15-25.

Fallahi, E and Simons, B R (1995) Rootstock, time, technique, and quantity of nitrogen effects on production, mineral nutrition, and postharvest quality of 'Fuji' apple [Abstract]. *HortScience*, **30**, 787.

Faust, M (1989) *Physiology of temperate zone fruit trees*. John Wiley, New York, NY.

Faust, M and Shear, C B (1972) Russeting of apples, an interpretative review. *HortScience,* **73**, 233-235.

Ferree, D C (2000) What determines fruit size. *American Fruit Grower*, **120**, 33-34.

Ferree, D C and Palmer, J W (1982) Effect of spur defoliation and ringing during bloom on fruiting, fruit mineral level, and net photosynthesis of 'Golden Delicious' apple. *Journal of the American Society for Horticultural Science*, **107**, 1182-1186.

Ferree, D C and Schmid, J C (2001) Chemical thinning 'Gala' apple in the midwest. *Journal American Pomological Society*, **55**, 109-113.

Fidler, J C; Wilkinson, B G; Edney, K L and Sharples, R O (1973) *The biology of apple and pear storage*. Research Review No. 3, Commonwealth Agricultural Bureaux, Farnham Royal, Slough, England.

Flore, J A (1978) Chemical thinning of Paulared and Jerseymac [apple cultivars]. *Compact Fruit Tree*, **11**, 115-119.

Forshey, C G (1976) Factors affecting chemical thinning of apples. New York's Food and Life Sciences Bulletin, No. 64.

Forshey, C G and Elfving, D C (1977) Fruit numbers, fruit size, and yield relationships in 'McIntosh' apples. *Journal of the American Society for Horticultural Science*, **102**, 399-402.

Forshey, C G; Elfving, D C and Stebbins, R L (1992) *Training and pruning of apple and pear trees*. American Society of Horticultural Science, Alexandria, Vancouver.

Forsythe, H Y and Hall, F R (1972) Control of the Plum Curculio in Ohio. *Journal of Economic Entomology*, **65**, 1703-1706.

Francesconi, A H D; Lakso, A N; Nyrop, J P; Barnard, J and Denning, S S (1996) Carbon balance as a physiological basis for the interactions of European red mite and crop load on 'Starkrimson Delicious' apple trees. *Journal of the American Society for Horticultural Science*, **121**, 959-966.

Frappell, B D and O'Loughlin, J B (1962) The harvest and storage of pears. *Tasmanian Journal of Agriculture*, **33**, 70-77.

Garriz, P I; Colavita, G M and Alvarez, H L (2000) Influence of crop level on growth and quality of 'Braeburn' apple fruit [Abstract]. *HortScience*, **35**, 418-419.

Génard, M and Lescourret, F (2004) Modelling fruit quality: ecophysiological, agronomical and ecological perspectives. In: *Production practices and quality assessment of food crops, Volume 1, Preharvest practice* (R Dris and S M Jain (eds.)), Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 47-82.

George, A P; Hieke, S; Rasmussen, T and Lüdders, P (1996) Early shading reduces fruit yield and late shading reduces quality in low-chill peach (Prunus persica (L.) Batsch) in subtropical Australia. *Journal of Horticultural Science*, **71**, 561-571.

Gillard, P; Jones, K; Bound, S and Oakford, M (1997) The Apple Thinning Program. *'Knowledge Acceleration', 1997 XpertUser Conference, Nov 2 - 5 Boston MA, USA.*

Goffinet, M C; Lakso, A N and Robinson, T L (1996) Fruit drop in 'Empire' apple by position within the cluster in unthinned trees vs trees thinned to single-fruited clusters. *HortScience*, **31**, 665.

Goffinet, M C; Robinson, T L and Lakso, A N (1995) A comparison of 'Empire' apple fruit size and anatomy in unthinned and hand-thinned trees. *Journal of Horticultural Science*, **70**, 375-387.

Greene, D W (1999) Tree growth management and fruit quality of apple trees treated with prohexadione-calcium (BAS 125). *HortScience*, **34**, 1209-1212.

Greene, D W (1993a) Effects of GA_4 and GA_7 on flower bud formation and russet development on apples. *Journal of Horticultural Science*, **38**, 171-176.

Greene, D W (1993b) A review of the use of benzyladenine (BA) as a chemical thinner for apples. *Acta Horticulturae*, **329**, 231-236.

Greene, D W and Autio, W R (1994) Combination sprays with benzyladenine to chemically thin spur-type 'Delicious' apples. *HortScience*, **29**, 887-890.

Greene, D W and Lord, W J (1983) Effects of dormant pruning, summer pruning, scoring, and growth regulators on growth, yield, and fruit quality of 'Delicious' and 'Cortland' apple trees. *Journal of the American Society for Horticultural Science*, **108**, 590-595.

Greene, D W; Autio, W R and Miller, P (1990) Thinning activity of benzyladenine on several apple cultivars. *Journal of the American Society for Horticultural Science*, **115**, 394-400.

Greene, D W; Autio, W R; Erf, J A and Mao, Z Y (1992) Mode of action of benzyladenine when used as a chemical thinner on apples. *Journal of the American Society for Horticultural Science*, **117**, 775-779.

Greenhalgh, W J and Godley, G L (1976) Studies of fruit shape in apples: a survey of factors influencing the development of 'Typiness' of the cultivar 'Red Delicious'. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **16**, 592-595.

Greenhalgh, W J; Godley, G L and Menzies, R (1977) Studies of fruit shape in apples: response to gibberellins and cytokinin sprays. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **17**, 505-509.

Gupta, G K (1983) Behaviour of fungicides and various spray schedules in the control of apple scab. *International Journal of Tropical Plant Diseases*, **1**, 181-185.

Han, S G and Yoon, T M (2001) Light distribution within the canopy and fruit quality in dwarf apple orchards [Abstract]. *Journal of the Korean Society for Horticultural Science*, **42**, 78-82.

Hansen, M (1997) Crop load, nutrition, tied to fruit quality disorders. *Good Fruit Grower*, **48**, 34-35.

Hassall & Associates Pty Ltd (2001) The Australian apple squeeze: a study by Hassall & Associates. Prepared for the Australian Government Department of Agriculture, Fisheries and Forestry, June 2001.

Hatch, A H (1975) The Influence of Mineral Nutrition and Fungicides in Russeting of ‘Goldspur’ Apple Fruit. *Journal of the American Society for Horticultural Science.* **100**, 52-55.

Hayashi, F; Naho, R; Bukovac, M J and Sell, H M (1968) Occurrence of gibberellin A_3 in parthenocarpic apple fruit. *Plant Physiology*, **43**, 448-450.

Hildebrand, E M (1944) The mode of action of the pollenicide elgetol. *Proceedings of the American Society for Horticultural Science*, **45**, 53-58.

Hoad, G V and Abbott, D L (1986) Hormonal control of growth and reproductive development in apple. In: *The regulation of photosynthesis in fruit trees* (Lakso, A N and Lenz, F, (Eds)). Symposium Proceedings NY State Agricultural Experimental Station, Geneva, NY, USA, 87-92.

Hong, K H; Kim, Y S; Yiem, M S; Kim, T C and Choi, J S (1989) The effects of kind of fruit bag and bagging date on fruit quality of *Whangkeum Bae* pear [Abstract]. *Research Report, Naju Branch Station, Horticultural Experiment Station, Naju, Korea Republic*, **31**, 26-33.

Hoyt, S C; Tanigoshi, L K and Browne, R W (1979) Economic injury level studies in relation to mite on apple. *Recent Advances in Acarology*, **1**, 3-12.

Hudina, M and Stampar, F (2000) Influence of leaf area on the sugar and organic acids content in pear fruits (*Pyrus communis* L.) cv. ‘Williams’. *Eighth International Symposium on Pear, Ferrara-Bologna, Italy, 4-9 September 2000*.

Hull, L A and Beers, E H (1990) Validation of injury thresholds for European red mite (Acari:Tetranychidae) on 'Yorking' and 'Delicious' apple. *Journal of Economic Entomology*, **83**, 2026-2031.

Irving, D E; Pallesen, J C; Drost, J H (1989) Preliminary results on chemical thinning of apple blossoms with ammonium thiosulphate, NAA and ethephon. *New Zealand Journal of Crop and Horticultural Science*, **17**, 363-365.

Jackson, J E (1970) Individual fruit size in relation to age of bearing wood on 'Laxton's Superb’ apple trees. *East Malling Research Station annual report for 1969*, 83-85.

Jackson, J E (1968) Effects of shading on apple fruits. *Report East Malling Research Station for 1967*, 69-73.

Jackson, J E (1967) Variability in fruit size and colour within individual trees. *Report East Malling Research Station for 1966*, 110-115.

Jackson, J E and Hamer, P C (1980) The causes of year-to-year variation in the average yield of Cox's Orange Pippin apple in England. *Journal of Horticultural Science*, **55**, 149-156.

Jackson, J E and Palmer, J W (1977a) Effects of shade on the growth and cropping of apple trees. I Experimental details and effects on vegetative growth. *Journal of Horticultural Science*, **52**, 245-252.

Jackson, J E and Palmer, J W (1977b) Effects of shade on the growth and cropping of apple trees. II Effects on components of yield. *Journal of Horticultural Science*, **52**, 253-266.

Jackson, J E; Hamer, P C and Wickendon, M F (1983) Effects of early spring temperatures on the set of fruits of Cox's Orange Pippin apple and year-to-year variation in its yields. *Acta Horticulturae*, **139**, 75-82.

Jackson, J E; Palmer, J W; Perring, M A and Sharples, R O (1977) Effects of shade on the growth and cropping of apple trees. III Effects on fruit growth, chemical composition and quality at harvest and after storage. *Journal of Horticultural Science*, **52**, 267-282.

Johnson, D S (1995) Effect of flower and fruit thinning on the maturity of ‘Cox’s Orange Pippin’ apples at harvest. *Journal of Horticultural Science*, **70**, 541-548.

Johnson, D S (1994) Influence of time of flower and fruit thinning on the firmness of 'Cox's Orange Pippin' apples at harvest and after storage. *Journal of Horticultural Science*, **69**, 197-203.

Johnson, D S (1992) The effect of flower and fruit thinning on the firmness of 'Cox's Orange Pippin' apples at harvest and after storage. *Journal of Horticultural Science*, **67**, 95-101.

Jones, K M (1979) The effect of Promalin (giberellins GA_{4+7} and the cytokinin 6-benzyladenine) on the typiness and dimensions of ‘Richared’ apples. *Department of Agriculture, Tasmania, Report No. 62609*.

Jones, K M and Koen, T B (1985) Temperature effects on ethephon thinning of apples. *Journal of Horticultural Science*, **60**, 21-24.

Jones, K; Bound, S and Miller, P (1998) *Crop regulation of pome fruit in Australia*. Tasmanian Institute of Agricultural Research. Hobart. ISBN 1-86295-027-X.

Jones, K M; Bound, S A and Oakford, M J (1992a) Identifying the optimum thinning time for red 'Fuji' apples. *Journal of Horticultural Science*, **67**, 685-694.

Jones, K M; Bound, S A; Gillard, P and Oakford, M J (1997a) A working model of apple thinning. *Acta Horticulturae,* **463***,* 475-480.

Jones, K M; Bound, S A; Koen, T B and Oakford, M J (1992b) Effect of timing of hand thinning on the cropping potential of red Fuji apple trees. *Australian Journal of Experimental Agriculture*, **32**, 417-420.

Jones, K M; Bound, S A; Oakford, M J and Gillard, P (2000) Modelling thinning of pome fruits. *Plant Growth Regulation,* **31**, 75-84.

Jones, K M; Bound, S A; Oakford, M J and Wilson, D (1994) A strategy for reducing russet in red Fuji apples while maintaining control of black spot (*Venturia inaequalis*). *Australian Journal of Experimental Agriculture*, **34**, 127-130.

Jones, K M; Bound, S A; Summers, C R and Oakford, M J (1997b) Preliminary examination of thinning strategies on young ‘Jonagold’ and ‘Pink Lady’ apples. *Australian Journal of Experimental Agriculture*, **37**, 377-382.

Jones, K M; Graham, B; Bound, S A and Oakford, M J (1993) Preliminary trials to examine the effects of ethephon as a thinner of ‘Gala’ and ‘Jonagold’ apples. *Journal of Horticultural Science*, **68**, 139-147.

Jones, K M; Koen, T B; Bound, S A and Oakford, M J (1991a) Some reservations in thinning Fuji apples with naphthalene acetic acid (NAA) and ethephon. *New Zealand Journal of Crop and Horticultural Science*, **19**, 225-228.

Jones, K M; Koen, T B; Bound, S A; Oakford, M J; Pettenon, S and Rudge, T (1991b) Effects of paclobutrazol and carbaryl on the yield of Hi-Early red ‘Delicious’ apples. *Journal of Horticultural Science*, **66**, 159-163.

Jones, K M; Koen, T B and Meredith, R J (1983) Thinning Golden Delicious apples using ethephon sprays. *Journal of Horticultural Science*, **58**, 381-388.

Jones, K M; Koen, T B; Longley, S B and Oakford, M J (1988) Thinning 'Golden Delicious' apples with naphthalene acetic acid in relation to spray concentration, volume and time of day. *Journal of Horticultural Science*, **63**, 27-30.

Jones, K M; Koen, T B; Oakford, M J and Bound, S A (1989) Thinning 'red Fuji' apples with ethephon and NAA. *Journal of Horticultural Science*, **64**, 527-532.

Kader, A A (2002) Fruits in the global market. In: *Fruit quality and its biological basis* (M Knee (ed.)), Sheffield Academic Press, Sheffield, pp 1-16.

Kader, A A (1999) Fruit maturity, ripening, and quality relationships. *Acta Horticulturae*, **485**, 203-208.

Katzler, H and Wurm, L (1998) Effects of different pruning measures on yield and outer and inner fruit quality with the apple cultivars Jonagold and Golden Delicious [Abstract]. *Mitteilungen Klosterneuburg, Rube und Wein, Obstbau und Fruchteuerwertung*, **48**, 137-144.

Kikuchi, T; Arakawa, O and Norton, R N (1997) Improving skin colour of 'Fuji' apple in Japan. *Fruit Varieties Journal*, **51**, 71-75.

Kirby, A H M and Bennett, M (1967) Susceptibility of apple and pear varieties to damage by certain organic fungicides. *Journal of Horticultural Science*, **42**, 117-131.

Kirby, A H M; Butt, D J and Williamson, C J (1970) Trials in 1968 of new fungicides on apple and pear. *Report of the East Malling Research Station for 1969*, 171-176.

Knight, J N (1986) Fruit thinning with carbaryl. *Acta Horticulturae*, **179**, 707-708.

Knight, J N (1980) Fruit thinning of the apple cultivar, Cox's Orange Pippin. *Journal of Horticultural Science*, **55**, 267-273.

Koen, T B; Jones, K M and Longley, S B (1988) Spray thinning strategies for 'Red Delicious' apple using naphthalene acetic acid and ethephon. *Journal of Horticultural Science*, **63**, 31-35.

Koen, T B; Jones, K M and Oakford, M (1986) Model building for prediction of ethephon thinning effects. *Acta Horticulturae*, **179**, 645-652.

Koike, H; Tamai, H; Ono, T and Shigehara, I (2003) Influence of time of thinning on yield, fruit quality and return flowering of 'Fuji' apple. *Journal American Pomological Society*, **57**, 169-173.

Kupferman, E (2002) Critical aspects of harvest and quality management. Washington State University – Tree Fruit Research and Extension Centre, Postharvest information Network. Downloaded 1 July 2004 http://postharvest.tfrec.wsu.edu/EMK2002A.pdf.

Lakso, A N; Corelli Grappadelli, L; Barnard, J and Goffinet, M C (1995) An expolinear model of the growth of the apple fruit. *Journal of Horticultural Science*, **70**, 389-394.

Lakso, A N; Mattii, G B; Nyrop, J P and Denning, S S (1996) Influence of European red mite on leaf and whole-canopy carbon dioxide exchange, yield, fruit size, quality, and return cropping in 'Starkrimson Delicious' apple trees. *Journal of the American Society for Horticultural Science*, **121**, 954-958.

Lakso, A N; Robinson, T L; Goffinet, M C and White, M D (2001) Apple fruit growth responses to varying thinning methods and timing. *Acta Horticulturae*, **557**, 407-412.

Letham, D S (1961) Influence of fertiliser treatment on apple fruit composition and physiology. I. Influence on cell size and cell number. *Australian Journal of Agricultural Research*, **12**, 600-611.

Li, K T; Lakso, A N; Piccioni, R and Robinson, T (2003a) Summer pruning reduces whole-canopy carbon fixation and transpiration in apple trees. *Journal of Horticultural Science & Biotechnology*, **78**, 749-754.

Li, K T; Lakso, A N; Piccioni, R and Robinson, T (2003b) Summer pruning effects on fruit size, fruit quality, return bloom and fine root survival in apple trees. *Journal of Horticultural Science & Biotechnology*, **78**, 755-761.

Lienk, S E; Chapman, P and Curtis Jr, O F (1956) Responses of apple trees to mite infestations. *Journal of Economic Entomology*, **49**, 350-353.

Link, H (2000) Significance of flower and fruit thinning on fruit quality. *Plant Growth Regulation*, **31**, 17-26.

Link, H (1993) Influence of pruning on fruit quality and storage potentials of apples. *Acta Horticulturae*, **326**, 29-38.

Link, H (1967) Chemisches Ausdunnen mit Pantrin und Geramid Neu [Abstract]. *Mitt. Obstbau*, **11**, 96-101.

Little, C (1999) Apple and pear maturity manual. Colin R Little, Sherbrooke, Victoria, Australia. 118 pp.

Llewelyn, F W M (1968) The effect of partial defoliation at different times in the season on fruit drop and shoot growth in Lord Lambourne apple trees. *Journal of Horticultural Science*, **48**, 519-526.

Llewelyn, F W M (1966) The results of three years' spray and defoliation treatments, and their residual effects, on fruit retention in three apple varieties. *Report of the East Malling Research Station for 1965*, 125-127.

Llewelyn, F W M (1963) The importance of spur leaves and lime-sulphur sprays on fruit retention in three apple varieties. *Report of the East Malling Research Station for 1962*, 89-92.

Lombard, P B (1982) Pear pollination and fruit set. In: *The Pear – Cultivars to Marketing* (Eds T Van der Zwet and N F Childers) Horticultural Publications, Florida, 91-103.

Looney, N E (1993) Improving fruit size, appearance, and other aspects of fruit crop 'quality' with plant bioregulating chemicals. *Acta Horticulturae*, **329**, 120-127.

Looney, N E (1986) Chemical thinning of apples: some new strategies and important refinements to old procedures. *Acta Horticulturae*, **179**, 597-604.

Looney, N E (1979) Some effects of gibberellins A4+7 plus benzyladenine on fruit weight, shape, quality, Ca content, and storage behaviour of 'Spartan' apple. *Journal of the American Society for Horticultural Science*, **104**, 389-391.

Looney, N E and Knight, J N (1985) Effects of initial set and carbaryl treatment on final fruit set on 'Greensleeves' apple. *HortScience*, **20**, 400-401.

Looney, N E; Granger, R L; Chu, C L; McArtney, S J; Mander, L N and Pharis, R P (1992a) Influences of gibberellins A_4, A_{4+7}, and A_4 +iso-A_7 on apple fruit quality and tree productivity. I. Effects on apple russet and tree yield components. *Journal of Horticultural Science*, **67**, 613-618.

Looney, N E; Granger, R L; Chu, C L; McArtney, S J; Mander, L N and Pharis, R P (1992b) Influences of gibberellins A_4, A_{4+7}, and A_4 +iso-A_7 on apple fruit quality and tree productivity. II. Other effects on fruit quality and importance of fruit position within the tree canopy. *Journal of Horticultural Science*, **67** 814-847.

Lord, W L and Greene, D W (1982) Effects of summer pruning on the quality of 'McIntosh' apples. *HortScience*, **17**, 372-373.

Magein, H (1989) Growth and abscission dynamics of 'Cox's Orange Pippin' and 'Golden Delicious' apple fruits. *Journal of Horticultural Science*, **64**, 265-273.

Marguery, P and Sangwan, B S (1993) Sources of variation between apple fruits within a season, and between seasons. *Journal of Horticultural Science*, **68**, 309-315.

Marini, R P and Barden, J A (1982) Yield, fruit size, and quality of three apple cultivars as influenced by summer or dormant pruning. *Journal of the American Society for Horticultural Science*, **107**, 474-479.

Marini, R P; Pfeiffer, D G and Sowers, D S (1994) Influence of European red mite (Acari:Tetranychidae) and crop density on fruit size and quality and on crop value of 'Delicious' apples. *Journal of Economic Entomology*, **87**, 1302-1311.

Marsh, K B; Volz, R K; Cashmore, W and Reay, P (1996) Fruit colour, leaf nitrogen level, and tree vigour in 'Fuji' apples. *New Zealand Journal of Crop and Horticultural Science*, **24**, 393-399.

Martin, D and Lewis, T L (1952) The physiology of growth in apple fruits. III. Cell characteristics and respiratory activity of light and heavy crops. *Australian Journal of Scientific Research*, **B5**, 315-327.

Martin, D; Lewis, T L and Cerny, J (1964) Apple fruit cell numbers in relation to cropping alternation and certain treatments. *Australian Journal of Agricultural Research*, **15**, 905-919.

Mattheis, J P; Buchanan, D A and Fellman, J K (1996) Volatile emissions and quality of bagged 'Fuji' apples. *HortScience*, **31**, 638.

McArtney, S; Foote, K; Campbell, J; Palmer, J and McGill, S (2002) Investigation of bloom desiccants as organic thinners of apples. *Proceedings of the 1st National Organic Tree Fruit Research Symposium, May 31 and June 1, 2001, Grand Junction, Colorado, USA*.

McArtney, S; Palmer, J W and Adams, H M (1996) Crop loading studies with 'Royal Gala' and 'Braeburn' apples: effect of time and level of hand thinning. *New Zealand Journal of Crop and Horticultural Science*, **24**, 401-407.

McArtney, S; White, M; Letter, I and Campbell, J (2004) Individual and combined effects of shading and thinning chemicals on abscission and dry-matter accumulation of ‘Royal Gala’ apple fruit. *Journal of Horticultural Science & Biotechnology*, **79**, 441-448.

McKenzie, D W (1971) A survey of shape variation in some New Zealand apples. *New Zealand Journal of Agricultural Research*, **14**, 491-498.

McLaughlin, J M and Greene, D W (1984) Effects of BA, GA_{4+7}, and daminozide on fruit set, fruit quality, vegetative growth, flower initiation and flower quality of 'Golden Delicious' apples. *Journal of the American Society for Horticultural Science*, **109**, 34-39.

Meador, D B and Taylor, B H (1987) Effect of early season foliar sprays of GA4+7 on russeting and return bloom of 'Golden Delicious' apple. *HortScience*, **22**, 412-415.

Meheriuk, M; Prange, R K; Lidster, P D and Porritt, S W (1994) *Postharvest disorders of apples and pears.* Agricultural Canada Publication, Ottawa.

Micke, W C; Joseph, A G; Maxwell, V N and Yeager, J T (1990) Chemical thinning of 'Granny Smith' apple. *Horticultural Science*, **25**, 1121.

Middleton, S and McWaters, A (2002) Hail netting of apple orchards – Australian experience. *The Compact Fruit Tree*, **35**, 51-55.

Miller, P (1985) *Apple thinning in Australia*. Horticultural Research Institute, Knoxfield, Victorian Department of Agriculture and Rural Affairs.

Miller, P (1984) Russet of Golden Delicious apples and possible implications for Packham pears. Workshop notes, *Growing Quality Packhams*, Horticultural Research Institute, Knoxfield, Victoria.

Miller, S S (1982) Regrowth, flowering, and fruit quality of 'Delicious' apple trees as influenced by summer pruning. *Journal of the American Society for Horticultural Science*, **107**, 975-978.

Mink, G I (1973) The apple industry in Japan. *HortScience*, **8**, 81-86.

Moon, B W and Kim, C C (1986) Effects of NAA and carbaryl on fruit thinning of apples (*Malus domestica* Borkh). *Journal of the Korean Society for Horticultural Science*, **27**, 239-248.

Morgan, D C; Stanley, C J; Volz, R and Warrington, I J (1984) Summer pruning of 'Gala' apple: The relationships between pruning time, radiation penetration, and fruit quality. *Journal of the American Society for Horticultural Science*, **109**, 637-642.

Myers, S C (1990) Apple seed number increases calcium levels. *Fruit Grower*, **110**, 50-51.

Myers, S C and Ferree, D C (1983) Influence of time of summer pruning and limb orientation on yield, fruit size, and quality of vigorous 'Delicious' apple trees. *Journal of the American Society for Horticultural Science*, **108**, 630-633.

Noè, N and Eccher, T (1996) 'Golden Delicious' apple fruit shape and russeting are affected by light conditions. *Scientia Horticulturae*, **65**, 209-213.

Noga, G J and Bukovac, M J (1986) Impact of surfactants on fruit quality of 'Schattenmorelle' sour cherries and 'Golden Delicious" apples. *Acta Horticulturae,* **179**, 771-777.

Palmer, J W (1992) Effects of varying crop load on photosynthesis, dry matter production and partitioning of Crispin/M27 apple trees. *Tree Physiology*, **11**, 19-33.

Palmer, J W; Giuliani, R and Adams, H M (1997) Effect of crop load on fruiting and leaf photosynthesis of 'Braeburn'/M26 apple trees. *Tree Physiology*, **17**, 741-746.

Pavel, E W and Dejong, T M (1993) Source- and sink-limited growth periods of developing peach fruits indicated by relative growth analysis. *Journal of the American Society for Horticultural Science*, **118**, 820-824.

Perring, M A and Preston, A P (1974) The effect of orchard factors on the chemical composition of apples. III. Some effects of pruning and nitrogen application on Cox's Orange Pippin fruit. *Journal of Horticultural Science*, **49**, 85-93.

Polomski, R F; Barden, J A; Byers, R E and Wolf, D D (1988) Apple fruit nonstructural carbohydrates and abscission as influenced by shade and terbacil. *Journal of the American Society for Horticultural Science*, **113**, 506-511.

Priestley, C A (1962) *Carbohydrate resources within the perennial plant: their utilisation and conservation*. Technical Communication No. 27, Commonwealth Agricultural Bureaux, Farnham Royal, Bucks, England.

Proctor, J T A and Lougheed, E C (1976) The effect of covering apples during development. *HortScience*, **11**, 108-109.

Proctor, J T A and Palmer, J W (1991) The role of spur and bourse leaves of three apple cultivars on fruit set and growth and calcium content. *Journal of Horticultural Science*, **66**, 275-282.

Proctor, J T A and Schecter, I (1992) Effect of ovule damage on fruit development in three apple cultivars, *HortScience*, **27**, 18-19.

Quinlan, J D (1966) The effects of partial defoliation on the pattern of assimilate movement in an apple rootstock. *Report of the East Malling Research Station for 1965,* 128-129.

Quinlan, J D and Preston, A P (1971) The influence of shoot competition on fruit retention and cropping of apple trees. *Journal of Horticultural Science*, **46**, 525-534.

Quinlan, J D and Preston, A P (1968) Effects of thinning blossom and fruitlets on growth and cropping of Sunset apple. *Journal of Horticultural Science*, **43**, 373-381.

Ramirez, H (1979) *Effects of growth substances on some physiological processes in apple in relation to flower initiation*. Thesis, University of Bristol, UK.

Riesen, W and Husistein, A (1998) Influence of rootstocks on apple fruit quality. *Acta Horticulturae*, **466**, 161-166.

Robinson, D W (1974) Commercial Horticulture in Japan. *Scientific Horticulture*, **25**, 56-63.

Robinson, T (1994) Effect of pruning severity on apple tree growth, yield and yield efficiency. *HortScience*, **29**, 437.

Robinson, T L and Watkins, C B (2004) Cropload affects fruit quality of Honeycrisp apple [Abstract]. *HortScience*, **39**, 841-842.

Robinson, T L; Seeley, E J and Barritt, B H (1983) Effect of light environment and spur age on 'Delicious' apple fruit size and quality. *Journal of the American Society for Horticultural Science*, **108**, 855-861.

Rom, C R and Barritt B H (1987) Management of apple fruiting spurs for fruit quality and profitability. Part one: the importance of spurs. *Good Fruit Grower*, **38**, 14-20.

Sansavini, S; Bassi, D and Giunchi, L (1981) Tree efficiency and fruit quality in high density orchards. *Acta Horticulturae*, **114**, 114-136.

Saure, M (1990) External control of anthocyanin formation in apple. *Scientia Horticulturae*, **42**, 181-218.

Saure, M C (1987) Summer pruning effects in apple – a review. *Scientia Horticulturae*, **30**, 253-282.

Schechter, I; Proctor, J T A and Elfving, D C (1993) Characterisation of seasonal fruit growth of 'Idared' apple. *Scientia Horticulturae*, **54**, 203-210.

Schneider, G W (1978) Abscission mechanism studies with apple fruitlets. *Journal of the American Society for Horticultural Science*, **103**, 455-458.

Schneider, G W and Lasheen, A M (1973) NAA and Sevin on composition, development, and abscission of apple fruit. *HortScience*, **8**, 103-104.

Scholtens, A (1992) Summer pruning yields profit. *Fruitteelt Den Haag*, **82**, 24, 26-27.

Schumacher, R; Frankhauser, F and Stadler, W (1978) Chemical thinning and natural fruit drop by modifying fruit set [Abstract]. *Schweizerischke Zeitschrift fur-und weinbau*, **114**, 245-258.

Seeley, E J; Micke, W C and Kammereck, R (1980) 'Delicious' apple fruit size and quality as influenced by radiant flux density in the immediate growing environment. *Journal of the American Society for Horticultural Science*, **105**, 645-657.

Shabala, S and Wilson, S (2001) Fluctuations in light intensity modulate ion fluxes from grape berry mesocarp: direct evidence from microelectrode ion flux estimations. *Australian Journal of Grape and Wine Research*, **7**, 137-143.

Shahak, Y; Stern, R A; Gussakovsky, E E; Cohen, Y and Naor, A (2003) Light-modifying nets: assessed benefits in apple orchards [Abstract]. *HortScience*, **38**, 739.

Shaw, J K (1914) A study of variation in apples. *Mass. Agricultural Experimental Station Bulletin 149.*

Simons, R K (1959) Anatomical and morphological responses of four varieties of apples to frost injury. *American Society of Horticultural Science*, **71**, 11-24.

Simons, R K and Chu, M C (1978) Periderm morphology of mature 'Golden Delicious' apple with special reference to russeting. *Scientia Horticulturae,* **8**, 333-340.

Skene, D S (1982) The development of russet, rough russet and cracks on the fruit of the apple Cox's Orange Pippin during the course of the season. *Journal of Horticultural Science*, **57**, 165-174.

Slade, D A (1979) Russet of apples. A review of work undertaken at Massey University. *The Orchardist of New Zealand*, **52**, 58-59.

Smith, W H (1950) Cell multiplication and cell enlargement in the development of the flesh of apple fruit. *Annals of Botany*, **14**, 23-38.

Southwick, F W and Weeks, W D (1949) Chemical thinning of apples at blossom time and up to four weeks after petal fall. *Proceedings of the American Society for Horticultural Science*, **53**, 143-147.

Southwick, S; Weis, K G and Yeager, J T (1996) Bloom thinning 'Loadel' cling peach with a surfactant. *Journal of the American Society for Horticultural Science*, **121**, 334-338.

Stampar, F; Hudina, M; Usenik, V; Sturm, K and Zadravec, P (2001) Influence of black and white nets on photosynthesis, yield and fruit quality of apple (*Malus domestica* Borkh.). *Acta Horticulturae*, **557**, 357-361.

Stampar, F; Veberic, R; Zadravec, P; Hudina, M; Usenik, V; Solar, A and Osterc, G (2002) Yield and fruit quality of apples cv. 'Jonagold' under hail protection nets [Abstract]. *Gartenbauwissenschaft*, **67**, 205-210.

Stanley, C J; Tustin, D S; Lupton, G B; McArtney, S; Cashmore, W M and de Silva, H N (2000) Towards understanding the role of temperature in apple fruit growth responses in three geographical regions within New Zealand. *Journal of Horticultural Science & Biotechnology*, **75**, 413-422.

Stebbins, R (1989) Maturity of new apple varieties. *Good Fruit Grower*, **40**, 7-9.

Steel, R G D and Torrie, J H (1980) *Principles and procedures of statistics: a biometrical approach*. 2nd edition, McGraw-Hill, New York.

Steenkamp, J and Westraad, I (1988) Effect of gibberellin A_{4+7} on stem- and calyx-end russeting in 'Golden Delicious' apples. *Scientia Horticulturae,* **35**, 207-215.

Steenkamp, J; Zyl, H J van and Westraad, I (1984) A preliminary evaluation of various chemical substances for the control of calyx-end russeting in Golden Delicious apples. *Journal of Horticultural Science*, **59**, 501-505.

Stembridge, G E and Morrell, G (1972) Effect of gibberellins and 6-benzyladenine on the shape and fruit set of 'Delicious' apples. *Journal of the American Society for Horticultural Science*, **97**, 464-467.

Stiles, W C; Childers, N F and Prusik, M J (1959) Effects of urea sprays and pesticides on russeting and cracking of 'Stayman' apple. *American Society of Horticultural Science*, **74**, 25-29.

Stover, E (1992) Loss of Elgetol puts added pressure on thinning plants. *Good Fruit Grower*, **43**, 7-9.

Sugiura, T; Honjo, H and Horimoto, M (1995) Measuring cell size and estimating changes in the number of fruit cells by replica or video microscope. *HortScience*, **30**, 270-271.

Sullivan, D T (1965) The effect of time of bloom of individual flowers on the size, shape and maturity of apple fruits. *Proceedings of the American Society for Horticultural Science*, **87**, 41-46.

Talaie, A; Gharaghani, A and Asgari, M A (2004) The effects of four clonal rootstocks on growth indices, yield, fruit quality, and quantity of 'Golden Smoothee' apple in Iran's climate conditions. *HortScience*, **39**, 798.

Taylor, B K (1975) Effects of gibberellin sprays on fruit russet and tree performance of 'Golden Delicious' apples. *Journal of Horticultural Science,* **53**, 167-169.

Taylor, B H and Ferree, D C (1984) The influence of summer pruning and cropping on growth and fruiting of apple. *Journal of the American Society for Horticultural Science*, **109**, 19-24.

Terblanche, R D and Pienaar, W J (1977) The effect of pruning practice on the intensity of bitter pit in Cox's Orange Pippin. *Deciduous Fruit Grower*, **27**, 66-70.

Tomlin, C (Ed) (1994) *The Pesticide Manual*: 10^{th} edition. Crop Protection Publications, Bath.

Tromp, J (1997) Maturity of apple cv, Elstar as affected by temperature during a six-week period following bloom. *Journal of the American Society for Horticultural Science*, **72**, 811-819.

Tromp, J (1990) Fruit shape in apple under various controlled environment conditions. *Scientia Horticulturae*, **43**, 109-115.

Tukey, L D (1960) Atmospheric moisture causes russeted apples. *Science for the Farmer*, **7**, 6.

Tukey, R B (1970) Predicting the harvest size of Bartlett pears. *Washington State University Extension Publication E.M.3403*, 1-7.

Uitterlinden, L and Westerlaken, J (1970) The influence of pruning and chemical fruit thinning on Golden Delicious [Abstract]. *Fruitteelt*, **60**, 310-311.

Unrath, C R (1974) The commercial implication of gibberellin A4+7 plus benzyladenine for improving shape and yield of Delicious apples. *Journal of the American Society for Horticultural Science*, **99**, 381-384.

Utermark, H (1977) Summer pruning to control growth and maintain fruiting in mature apple trees. *Compact Fruit Tree*, **10**, 86-90.

van Zyl, H J (1970) Water and fruit quality. *The Deciduous Fruit Grower,* **20**, 143-146.

Veinbrants, N (1979) Growth regulator helps Delicious shapes. *Fruit World and Market Grower*, Jan, p10.

Veinbrants, N (1978) Growth regulator helps Delicious shapes. *Victorian Horticulture Digest,* **74**, 2-3.

Veinbrants, N and Miller, P (1981) Promalin improves the shape of Delicious apples in Victoria. *Australian Journal of Experimental Agriculture and Animal Husbandry*, **21**, 623-630.

Volz, R K and Ferguson, I B (1999) Flower thinning method affects mineral composition of 'Braeburn' and 'Fiesta' apple fruit. *Journal of Horticultural Science & Biotechnology*, **74**, 452-457.

Volz, R K; Ferguson, I B; Hewett, E W and Woolley, D J (1994) Wood age and leaf area influence fruit size and mineral composition of apple fruit. *Journal of Horticultural Science*, **69**, 385-395.

Wagenmakers, P S and Callesen, O (1995) Light distribution in apple orchard systems in relation to production and fruit quality. *Journal of Horticultural Science*, **70**, 935-948.

Warner, G (1995) Apple russeting has many possible causes. *Good Fruit Grower*, **46**, 15.

Warner, G (1993) New, environmentally-safe chemical thinner approved. *Good Fruit Grower*, **44**, 13-15.

Warrington, I J; Fulton, T A; Halligan, E A and deSilva, H N (1999) Apple fruit growth and maturity are affected by early season temperatures. *Journal of the American Society for Horticultural Science*, **124**, 468-477.

Warrington, I J; Stanley, C J; Tustin, D S; Hirst, P M and Cashmore, W M (1996) Light transmission, yield distribution, and fruit quality in six tree canopy forms of 'Granny Smith' apple. *Journal of Tree Fruit Production*, **1**, 27-54.

Warrington, I J; Stanley, C J; Volz, R and Morgan, D C (1984) Effects of summer pruning on Gala apple quality. *Orchardist of New Zealand*, **57**, 518-519, 522.

Way, D W (1971) Fruit thinning. *East Malling Research Station annual report for 1970*, 25.

Webster, A (1997) Fruit size and quality. *East Malling Research Association Members Day Report, April 1997*, 1-7.

Webster, D H and Crowe, A D (1971) Effect of shade treatments on 'McIntosh' apple shape. *Journal of the American Society for Horticultural Science*, **96**, 292-294.

Weeks, W D; Southwick, F W; Drake, M and Steckel, J E (1958) The effect of varying rates of N and potassium on the mineral composition of McIntosh foliage and fruit colour. *Journal of the American Society for Horticultural Science*, **71**, 11-19.

Wertheim, S J (1982) Fruit russeting in apple as affected by various gibberllins. *Journal of Horticultural Science*, **57**, 283-288.

Wertheim, S J (1974) Chemical thinning of apple. *Report for the Research Station for Fruit Growing, Wilhelminadorp for 1973*, 17-18.

Westwood, M N (1993) *Temperate-zone pomology: physiology and culture*. 3rd ed, Timber Press Inc., Portland, Oregon.

Westwood, M N and Blayney, L T (1963) Non-climatic factors affecting the shape of apple fruits. *Nature*, **200**, 802-803.

Westwood, M N and Burkhart, D J (1968) Climate influences shape of ‘Delicious’. *American Fruit Grower*, **88**, 26.

Westwood, M N; Batjer, L P and Billingsley, H D (1967) Cell size, cell number, and fruit density of apples as related to fruit size, position in cluster, and thinning method. *Proceedings of the American Society for Horticultural Science*, **91**, 51-62.

Widmer, A (2001) Light intensity and fruit quality under hail protection nets. *Acta Horticulturae*, **557**, 421-426.

Widmer, A (1997) Light conditions, assimilation and fruit quality under hail nets [Abstract]. *Obst und Weinbau*, **133**, 197-199.

Williams, M W (1993) Sulfcarbamide, a blossom thinner for apples. *Hort Technology*, **3**, 322-324.

Williams, M W (1986) Thinners, growth regulators impact fruit size. *The Goodfruit Grower*, **37**, 12-18.

Williams, M W (1979) Chemical thinning of apples. *Horticultural Reviews*, **1**, 270-299.

Williams, M W (1977) Adverse weather and fruit thinning can affect seed content and size of Red Delicious apples – what can growers do about it? *Proceedings of the seventy-third annual meeting of the Washington State Horticultural Association*, 157-159, 161.

Williams, M W and Edgerton, L J (1981) Fruit thinning of apples and pears with chemicals. *Agriculture Information Bulletin No. 289*, United States Department of Agriculture.

Williams, M W and Stahly, E A (1969) Effect of cytokinins and gibberellins on the shape of 'Delicious' apple fruits. *Journal of the American Society for Horticultural Science*, **94**, 17-19.

Williams, M W; Bound, S A; Hughes, J and Tustin, S (1995) Endothall, a blossom thinning agent for apples. *Hort Technology*, **5**, 257-259.

Wilton, J (1997) Growing large Royal Gala. *The Orchardist*, **70**, 13-15.

Wilton, J (1995) Russet and other blossom period issues. *The Orchardist*, **68**, 19-22.

Wilton, W J W (1989) Tree management – varying varietal needs. *The Orchardist*, **62**, 24-26.

Wismer, P T; Proctor, J T A and Elfving, D C (1995) Benzyladenine effects on cell division and cell size during apple fruit thinning. *HortScience*, **30**, 852.

Wundermann, H (1981) Plant protection chemicals and fruit russeting of Golden Delicious with reference to post-blossom treatments. *Obstbau*, **188**, 92.

Ystaas, J (1989) The effect of summer pruning on yield, fruit size and fruit quality of two apple cultivars [Abstract]. *Norsk Landbruksforsking*, **3**, 195-204.

Ystaas, J; Faust, M and Miller, S S (1992) Effects of summer pruning on yield, fruit size, and fruit quality of the apple cultivar 'Summerred'. *Acta Horticulturae*, **322**, 277-282.

Zwick, R W; Fields, G J and Mellenthin, W M (1976) Effects of mite population density on 'Newtown' and 'Golden Delicious' apple tree performance. *Journal of the American Society for Horticultural Science*, **101**, 123-125.

Appendix 1

Location Maps

1. Apple growing regions in Australia

2. Huon Valley trial sites

Downloaded 4 January 2005 from www.tased.edu.au/tot/s/huon.html

Appendix 2

Rainfall data for shade trials (Chapter 5)

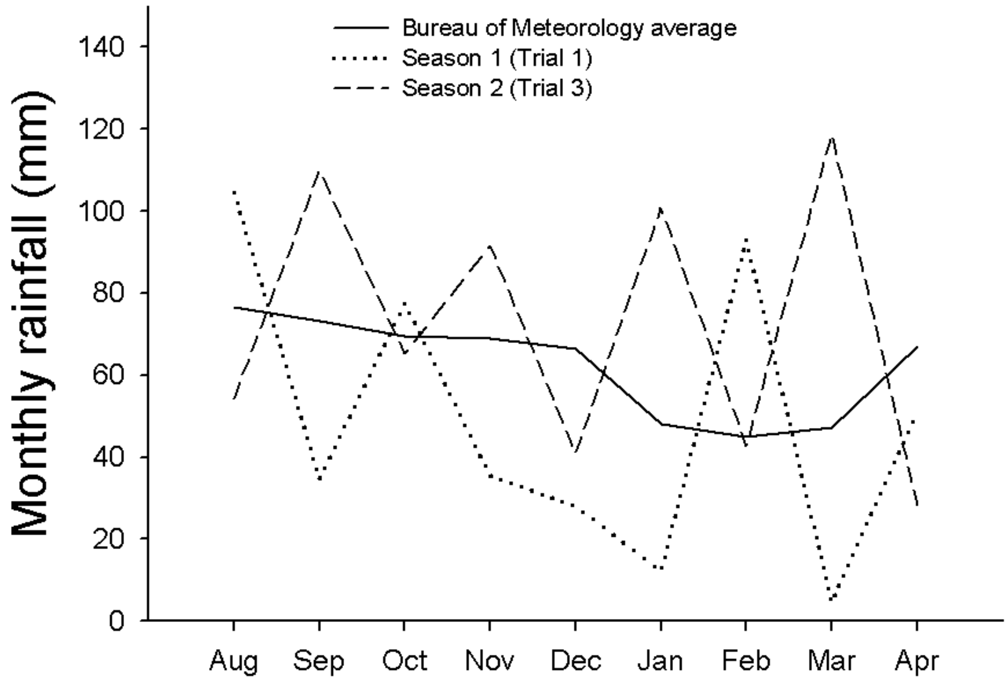


***Figure A2.1**: Monthly rainfall for Huon Valley trial sites*

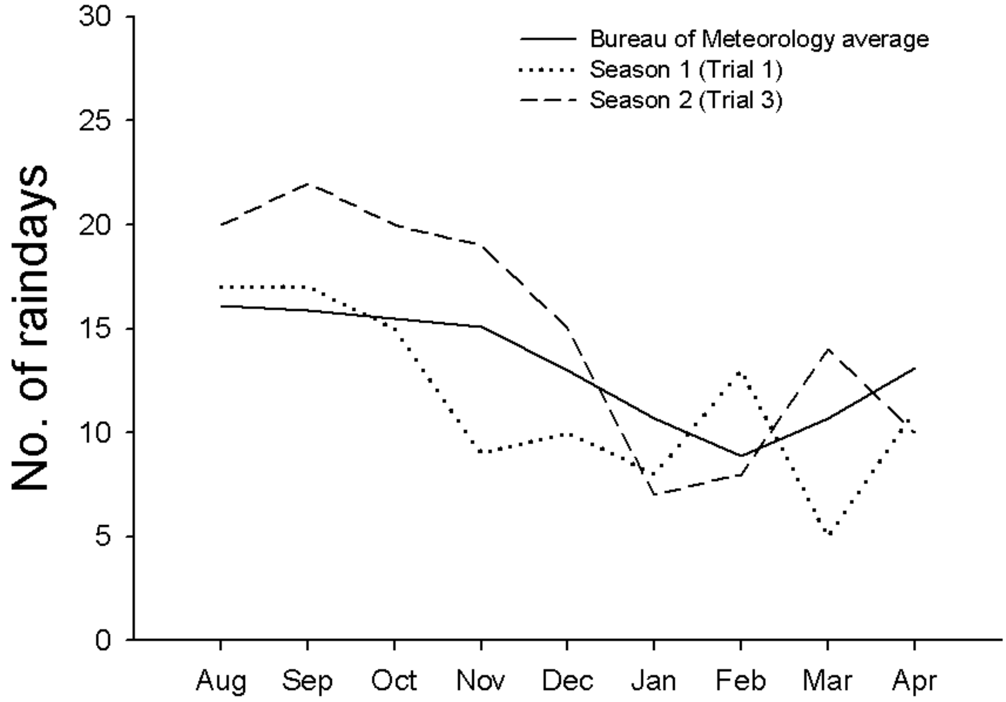


Figure A2.2: *Number of rain days for Huon Valley trial sites*

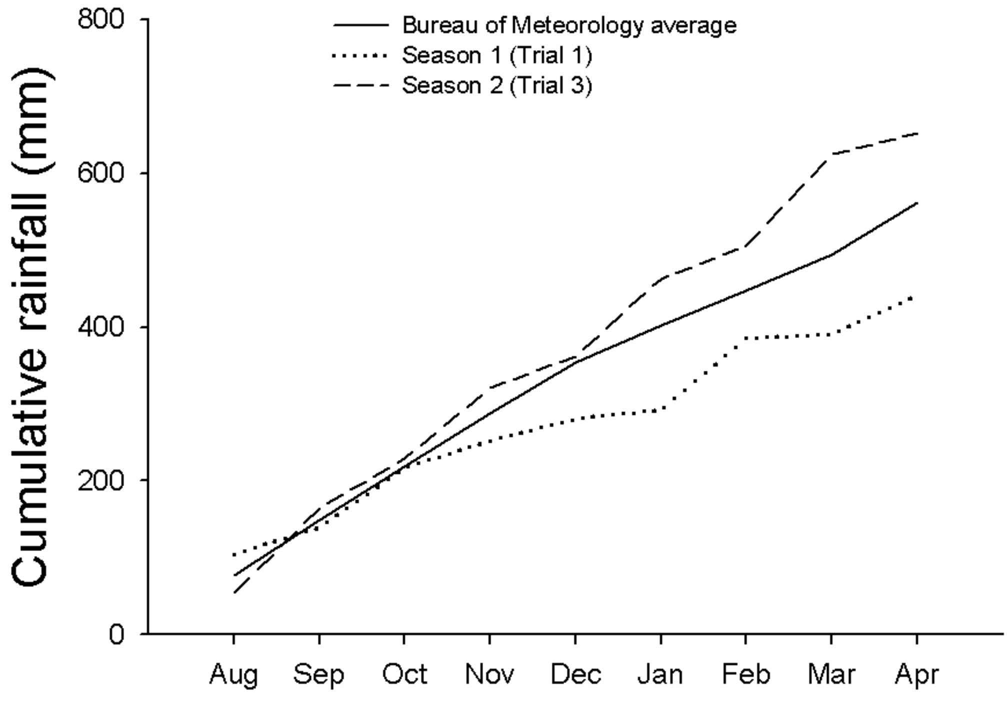


Figure A2.3: *Cumulative rainfall for Huon Valley trial sites*

Appendix 3

Climatic data for crop load trials (Chapter 6)

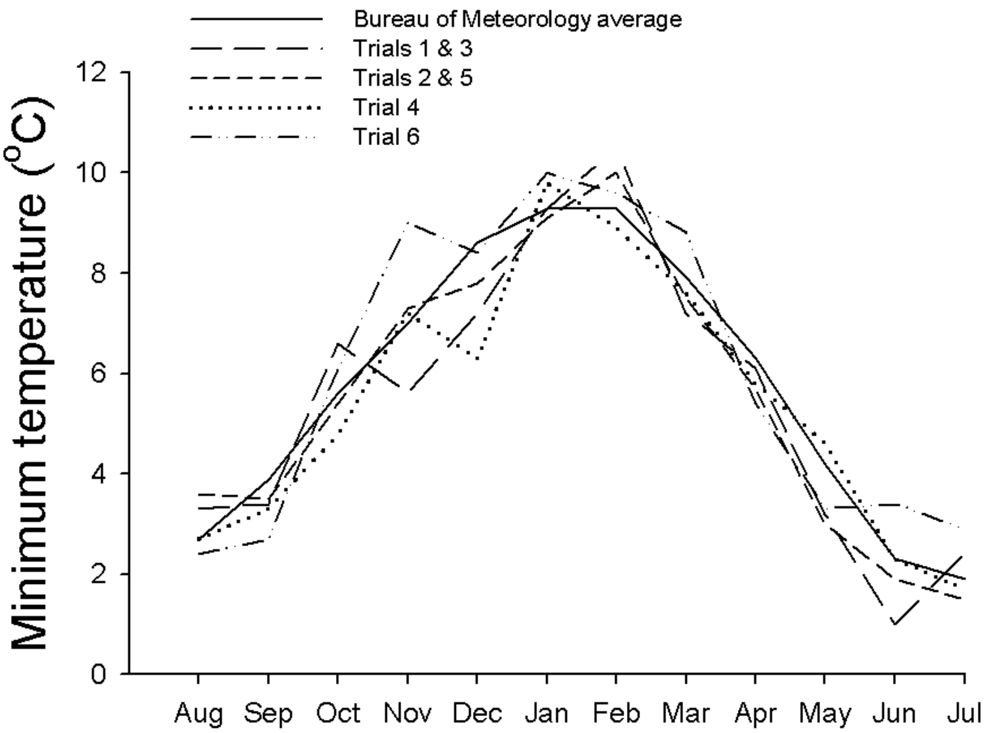


***Figure A3.1**: Minimum monthly temperatures for Huon Valley trial sites*

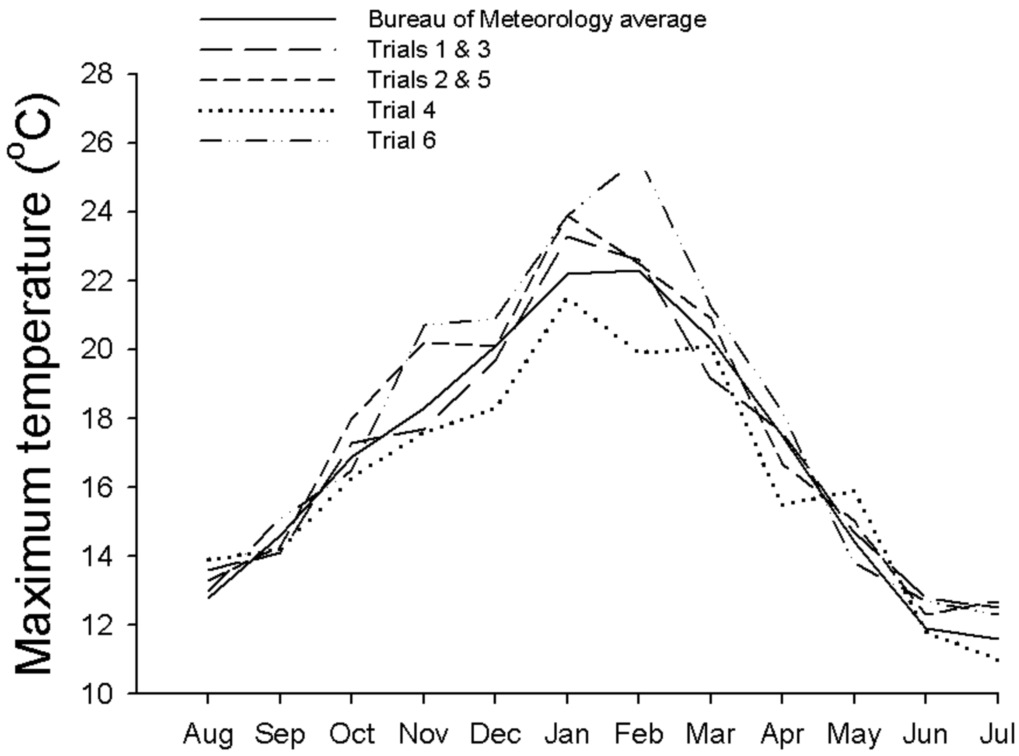


***Figure A3.2**: Maximum monthly temperatures for Huon Valley trial sites*

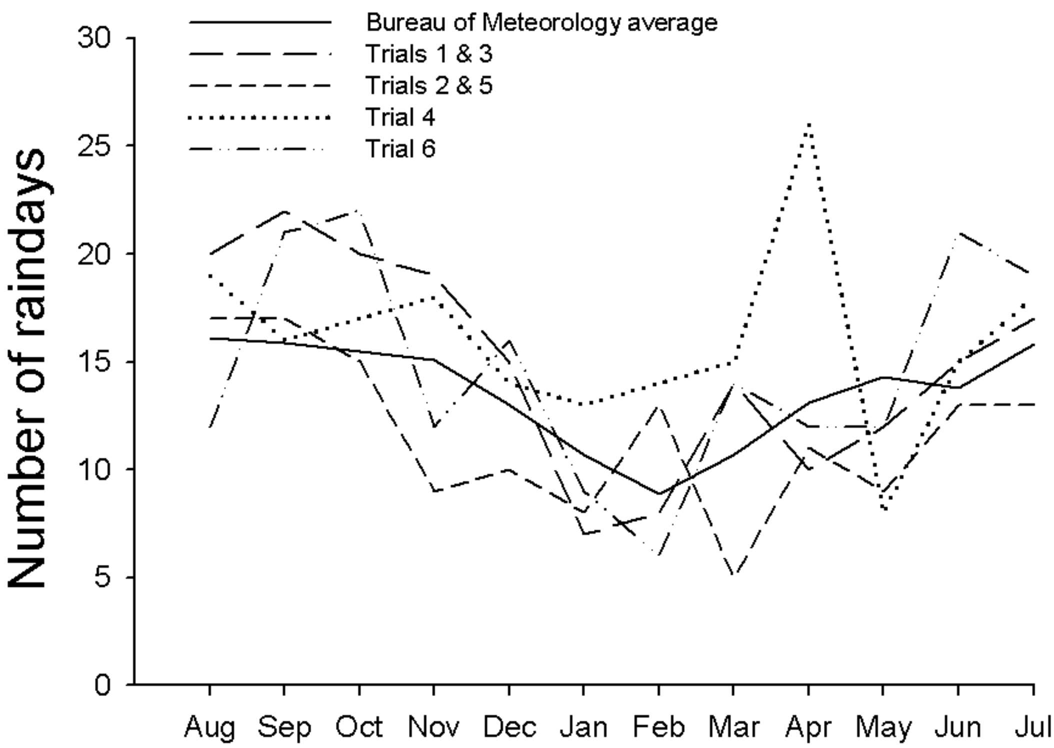


***Figure A3.3**: Number of raindays for Huon Valley trial sites*

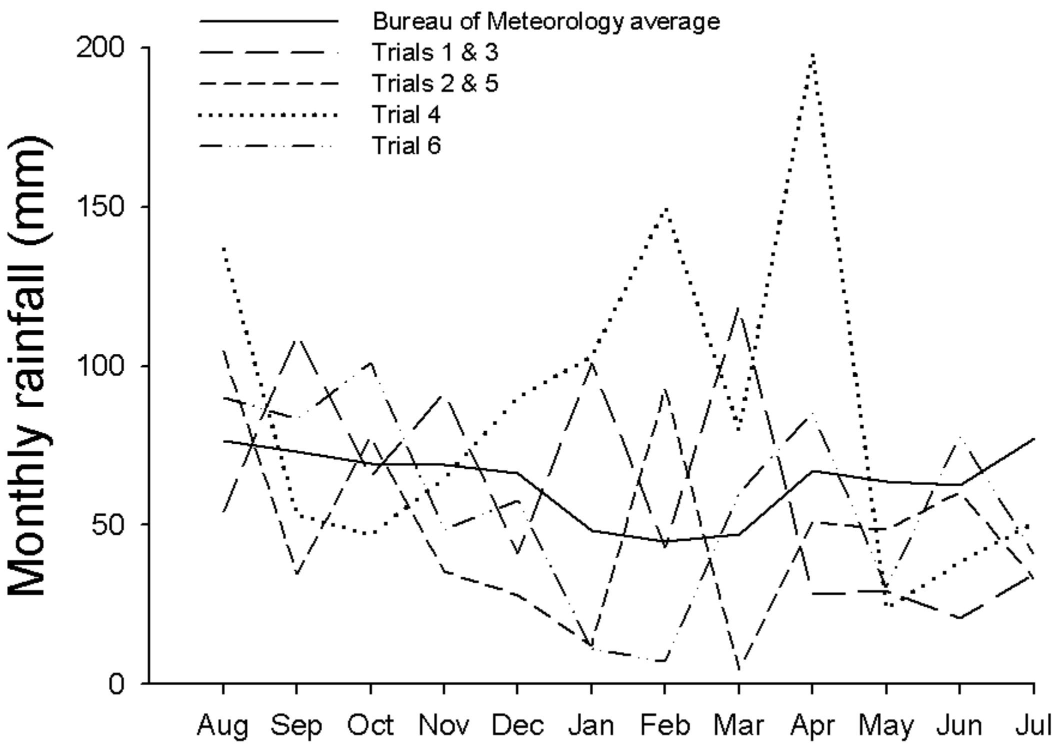


Figure A3.4: *Average monthly rainfall for Huon Valley trial sites*

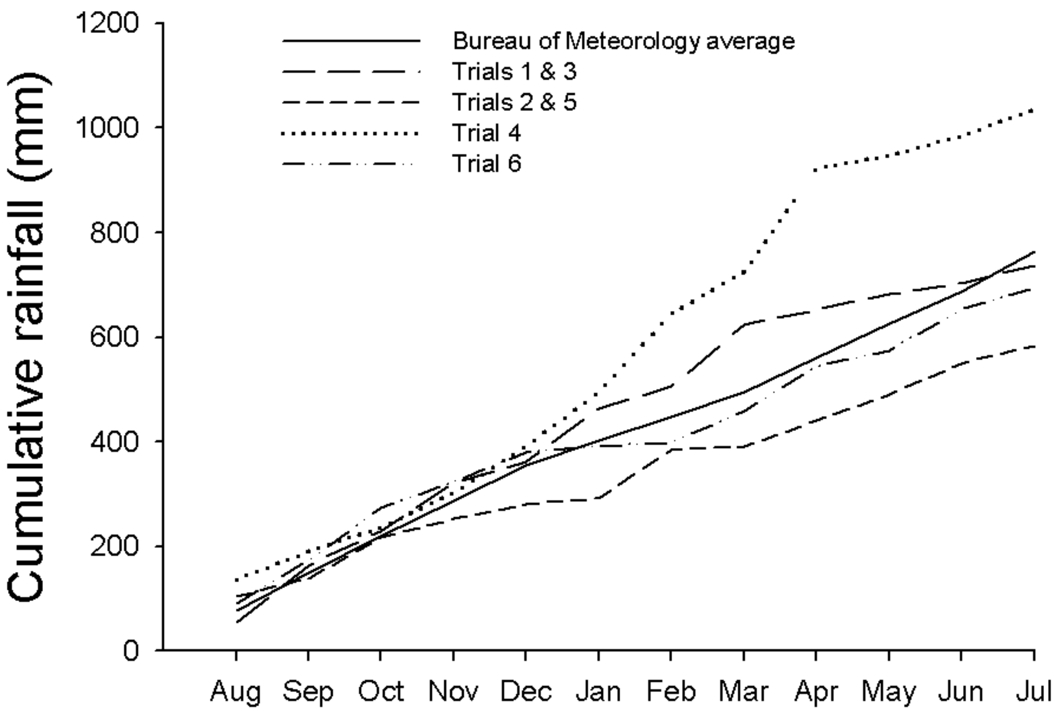
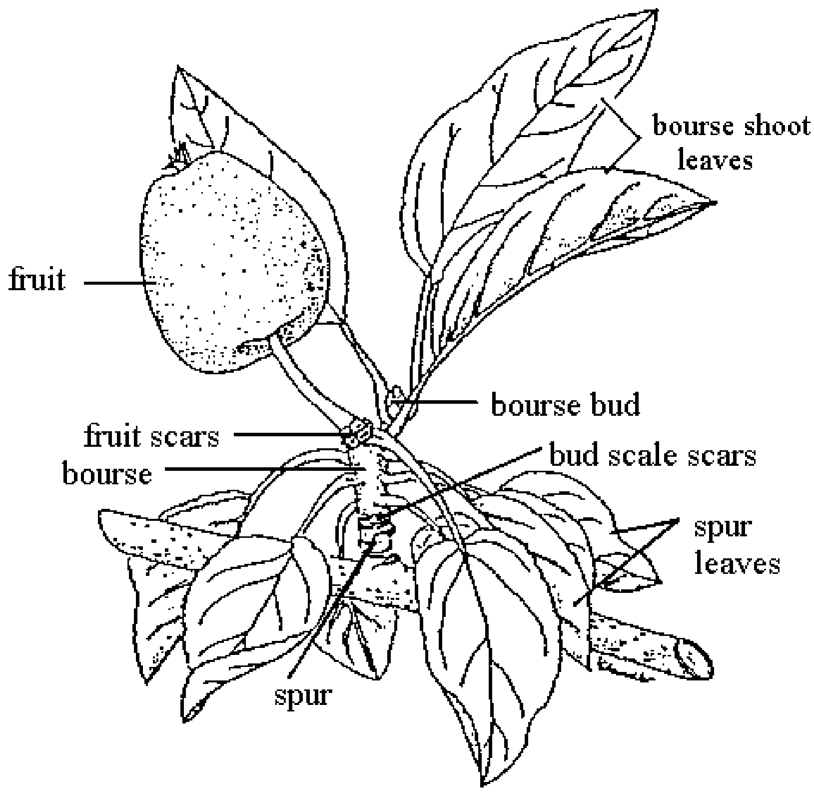


Figure A3.5: *Cumulative rainfall over the growing season for trial sites*

Appendix 4

Structure of apple spur (Chapter 8)



Taken from Rom, C R (1985) Bud development and vigour. *In* Pollination and fruit set, proceedings of the shortcourse, March 1985. Goodfruit Grower, Yakima, Washington.